PB83-240671

Characterization of the NOx and SO2 Control Performances, Southern Indiana Gas and Electric Co., A.B. Brown Unit No. 1
Volume 1. Program Results

GCA Corp., Bedford, MA. GCA Technology Div.

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

Jul 83

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-83-038a	2.	3. RECIPIENT'S ACCESSION NO. PB83 240671
4. TITLE AND SUBTITLE Characterization of the NOx and SO2 Control Performances; Southern Indiana Gas and Electric Company A. B. Brown Unit 1; Volume I. Program Results		5. REPORT DATE July 1983 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Edward F. Peduto, Jr., Robert R. Hall, and Guy Tucker		8. PERFORMING ORGANIZATION REPORT NO. GCA-TR-82-23-G(1)
9. PERFORMING ORGANIZATION NAME AND ADDRESS GCA/Technology Division 213 Burlington Road Bedford, Massachusetts 01730		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-02-3168, Task 46
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Task Final; 5/81 - 10/82 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is J. David Mobley, Mail Drop 61, 919/541-2578.

16. ABSTRACT The five-volume report gives results of a continuous emissions monitoring program at Southern Indiana Gas and Electric Company's (SIGECO's) A. B. Brown Power Plant, to characterize the NOx and SO2 control performances of Unit 1 in terms of process variables. NOx results show that the unit operated at significantly below 70 percent of the existing NOx standard (301 ng/J). Daily averages were 135-219 ng/J, with a mean of 163 ng/J. Thirty-day rolling averages were 160-167 ng/J. SO2 results indicate a mean removal efficiency of 88.0 percent and emissions of 344 ng/J for the north tower, and 86.5 percent and 391 ng/J (respectively) for the south tower. Thirty-day rolling averages were 85.8-90.5 percent and 85.3-88.0 percent for the north and south towers, respectively. Thirty-day rolling average SO2 outlet emission rates were 274-396 ng/J and 355-418 ng/J for the north and south towers, respectively. Volume I gives program results; Volume II, program documentation; Volume III, SO2 data reports for the north module; Volume IV, SO2 data reports for the south module; and Volume V, data reports for NOx.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Properties	Pollution Control	13B	14G
Coal	Electric Power Plants	Stationary Sources	21D	10B
Combustion	Scrubbers	Dual Alkali Scrubbing	21B	13I, 07A
Sulfur Oxides	Calcium Oxides		07B	
Nitrogen Oxides	Alkalies			07D
Analyzing			14B	

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 110
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

NUMBER 215702

FULL DOCUMENT PROCESSING

BATCH NUMBER 2 1 2 2 K

3. COL. CD. 5

2. SOURCE CODE EPAORD

4. ACCESSION NUMBER PB83 240671

2A. RECOGNITION NUMBER #EPA-600-7-83-038A-V1

10. TRANSACTION N NEW D DUPLICATE P PRIOR S SUPERSEDES
N
10A.

6. MGT. CD.

C	D	A	R	K	V
Q	Q	K	V	K	

7. PROCESS ACCTG. CD. 00

7A. REGISTRATION FEE

8. PROD. MGR. H

9. RECEIPT TYPE 1
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9A. LOAN DUE OUT Y Y D D D

8/8

11. PRICE 1. STD. 2. EXC.

12. RETURNS 0 N/A 1 PAGES 3 REPRO 4 SDS 5 REST. 6 MISC.

12A. RETURN DATE Y Y M M D D

13. PROCESS 0
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14. PAT. POTENTIAL 0 NO 1 POOR 2 FAIR 3 GOOD 4 EXCEL.

16. BILL

17. FORM/PRICE

18. ANNOUNCE GRA WGA 0 D/S

19. PUBLICATION-1 U 24

20. PUBLICATION-2

20A. PUBLICATION-3

21. LIMITATION 0 N/A 1 DISCLAIMER 2 COLOR 3 COMBO

23. PC 00 BIN 0 STOCK 0N

24A. PAGES/SHEETS 110

PRICE CODE A06

DOMESTIC PRICE

FOREIGN PRICE

ACTION CD.

MICROFICHE

37. REL. CD.

38. MF PRINT

40. PRINT PC

39. ADD. INFO. Y

43. 43A) ORDER ADD'L STOCK & CODE/ADDR 43B) BIN MSG 43C) STK UNIT COST 43D) SET ID 43E) CAMERA CONTROL 43F) REFER TO ADDR

43B) Part of a 5

PB83-240689

RD Vol II

41. PC DUE

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42B. SUPPLIER SOURCE

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44. BATCH NO.

02C) COM. CAT.

03S) ADDITIONAL SOURCE CLIENTS

03L) LANGUAGE

03C) COMP. ENTRY CODE

34) SERIAL

35) CORP. AUTHOR CD.

U.S. AUTH.

MGT. CD. CAT REV KEY VER

45. REMARKS (DO NOT KEY)

FULL DOCUMENT PROCESSING

OL NUMBER 215701.

BATCH NUMBER 21712K

2. SOURCE CODE EPAŌRD

3. COL. CD. 5

4. ACCESSION NUMBER PB83-240663

2A. RECOGNITION NUMBER #Chara - of the NŌX-5V set

10. TRANSACTION N NEW D DUPLICATE P PRIOR S SUPERSEDES: N

10A.

6. INST. CD. C D A R K V: O X K V H

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7. PROCESS ACCTG. CD. 9

7A. REGISTRATION FEE

8. PROD. MGR. H

9. RECEIPT TYPE 0 N/A 1 RETAIN 2 LAST 3 ERRATA 4 LOAN

9A. LOAN DUE OUT Y Y D D D

11. PRICE 1. STD. 2. EXC.

12. RETURNS 0 N/A 1 PAGES 3 REPRO 4 EDS 5 REST. 6 MISC.

12A. RETURN DATE Y Y M M D D

13. PROCESS 0 STANDARD 1 INVENTORY 2 HIGHLIGHT 3 UNEDIT 4 REANNOUNCE 5 SPECIAL BB: 0

14. PAT. POTENTIAL 0 NO 1 POOR 2 FAIR 3 GOOD 4 EXCEL.

16. BILL

17. FORM/PRICE 12091

18. ANNOUNCE GRA 0 WGA 9 D/S 1

19. PUBLICATION-1 U 24

20. PUBLICATION-2

20A. PUBLICATION-3

21. LIMITATION 0N/A 1DISCLAIMER 2COLOR 3COMBO

22. PC 0 BIN 0 0 STOCK 00 24A. N PAGES/SHEETS 1279 PRICE CODE E99 V04 DOMESTIC PRICE 9100 FOREIGN PRICE 18209 ACTION CD. RŌ XM

MICROFICHE 37. REL. CO. 38. MF PRINT

39. ADD. INFO. Y

40. PRINT PC

41. PC/DUE

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43. 43A) ORDER ADD'L STOCK & CODE/ADDR 43B) BIN MSG 43C) STK UNIT COST 43D) SET ID 43E) CAMERA CONTROL 43F) REFER TO ADDR

43B) Manual handling - SET includes
5 vols.:
PB 83 - 240671 thru
PB 83 - 240713.

SET SHEET

RD

44. BATCH NO.

62C) COM. CAT.

63S) ADDITIONAL SOURCE CLIENTS

63L) LANGUAGE

63C) COMP. ENTRY CODE

34) SERIAL

35) CORP. AUTHOR CD.

U.S. AUTH.

MGT. CD. CAT REV KEY VER

45. REMARKS (DO NOT KEY)

JAN 80 NTIS-9-T

PB83-240671

EPA-600/7-83-038a
July 1983

CHARACTERIZATION OF THE NO_X AND SO_2 CONTROL PERFORMANCES; SOUTHERN INDIANA GAS & ELECTRIC CO., A.B. BROWN UNIT NO. 1:
Volume I. Program Results

by

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EPA Contract 68-02-3168
Taks No. 46

EPA Project Officer
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REPRODUCED BY
NATIONAL TECHNICAL
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U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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ABSTRACT

A continuous emissions monitoring program was conducted at the Southern Indiana Gas and Electric Company (SIGECO) A. B. Brown Power Plant. The primary purpose of this program was to characterize the NO_x and SO_2 control performances of unit No. 1 in terms of process variables.

Results for the NO_x segment of the program show that the unit operated significantly below 70 percent of the existing NO_x standard (301 ng/J). Daily averages ranged from 135 ng/J to 219 ng/J with the mean for the entire test program occurring at 163 ng/J. Thirty day rolling averages ranged from 160 ng/J to 167 ng/J.

Results for the SO_2 portion of the program indicate a mean removal efficiency of 88.0 percent and emissions of 344 ng/J for the north tower and a mean efficiency of 86.5 percent and emissions of 391 ng/J for the south tower. Thirty day rolling averages for the north tower ranged from 85.8 to 90.5 percent and for the south tower, 85.3 to 88.0 percent. Thirty day rolling average emission rates for outlet SO_2 ranged from 274 ng/J to 396 ng/J for the north tower and 355 ng/J to 418 ng/J for the south tower.

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ACKNOWLEDGMENTS

The authors extend their appreciation to Mr. J. David Mobley, the EPA Project Officer, and Mr. Peter Westlin of the Office of Air Quality Planning and Standards (OAQPS) for their guidance during the planning stages and conduct of the continuous monitoring program. We also acknowledge the Technical Support Staff of the Industrial Environmental Research Laboratory located at Research Triangle Park, North Carolina (IERL-RTP) who were responsible for outfitting the mobile laboratory utilized during the program. Special thanks are extended to Mr. Bruce Harris, Mr. James Montgomery and Mr. Wayne Fowler for their assistance in the field during setup, troubleshooting and site restoration.

Our appreciation is extended to Mr. James Vanmeter, Director of Power Production, and Mr. Thomas Durkin, A.B. Brown Plant Manager, for their hospitality and cooperation during the test program. Other SIGECO personnel responsible for the success of the data collection phase of the program included Mr. William Phelps, Mr. Richard Hughes and Mr. Keith Kinman.

Special thanks are extended to Mr. Karl Legatski and Mr. Will Boward of FMC Corportaion who assisted GCA in formulating a test approach, reviewing project data and assisting in the interpretation of the results. We also appreciate the assistance and guidance provided by Mr. Will Boward during his many trips to the A.B. Brown test site.

Finally we thank the GCA Personnel who were responsible for monitoring and sampling during this program. The authors thank Ms. Stephanie Diamond, Mr. Timothy Porter, Mr. Robert Encke, Mr. Paul Turina, Mr. Douglas Seeley, Ms. Susan Pendleton and Mr. Robert Preble for their dedicated effort. We also appreciate the efforts of Mr. Thomas Fitzgerald who conducted the statistical data analysis.

SECTION 1

INTRODUCTION

On June 11, 1979, the Environmental Protection Agency promulgated the New Source Performance Standards for Utility Steam Generators. These regulations are contained in Subpart Da of 40 CFR 60 and apply to utility steam generators for which construction was commenced after September 18, 1978.

Following promulgation of a standard, the EPA is required to assemble data and to conduct a review of the standard every 4 years. In preparation for this review, the Office of Air Quality Planning and Standards (OAQPS) initiated an overall program pertaining to the sulfur dioxide control standard. This program subsequently involved the testing of two dual alkali and two assisted wet scrubber systems to document the performance of high efficiency sulfur dioxide scrubber systems. These system types are considered "state-of-the-art" demonstrating consistently high sulfur control performance. Dual alkali facilities tested were:

- Louisville Gas and Electric--Cane Run No. 6.
- Southern Indiana Gas and Electric--A. B. Brown No. 1.

The two lime scrubber systems tested were:

- Springfield City Utilities--Southwest No. 1.
- Monongahela Power--Pleasants No. 1.

In support of the overall OAQPS test program, the Emisions/Effluent Technology Branch of the Industrial Environmental Research Laboratory at Research Triangle Park, North Carolina (IERL/RTP) administered the two dual alkali scrubber test programs as well as the Springfield City Utilities Program. GCA/Technology Division was contracted by IERL/RTP to conduct the test program at the A. B. Brown test site. The primary objective of this program was to characterize the modular SO_2 collection efficiency of the FMC dual-alkali scrubber system and the NO_x performance of the Babcock and Wilcox (B&W) wall-fired boiler over an extended period of time (The initial target was 90 consecutive days of operation). Of secondary importance was the evaluation of the influence of boiler and scrubber process conditions on SO_2 and NO_x control. The study involved a planning stage, a field data collection phase, followed by an evaluation phase. Approximately 68 days of continuous data were collected.

GENERAL PROGRAM APPROACH

The technical program was designed to emphasize selected program objectives. The primary and most important objective was to determine the SO_2 collection efficiency of each of the two scrubber modules and the NO_x emissions from the B&W boiler. A secondary but important objective was to determine the influence of process parameters on SO_2 performance. Emissions of NO_x were also measured and the effects of any variations in flue gas oxygen or CO content were evaluated. However, since NO_x emissions were approximately 0.5 lb/10^6 Btu, no variations in the operation of the dual register burners were suggested. Under the suppart Da regulations, a plant which can demonstrate emissions limits of less than 75 percent of the standard (0.53 lbs/10^6 Btu) are exempt from the NO_x monitoring requirements.

The primary program data were acquired utilizing a mobile continuous emissions monitoring laboratory maintained by the Technical Support Staff of IERL/RTP. This system was used to acquire the appropriate emissions and diluent data at the inlets to and outlets from the parallel scrubber modules. Concurrent with the emissions data collection, applicable boiler and scrubber process data were continuously acquired. These data provided process documentation for the emissions data on a real time basis. The process and emissions data files were subsequently used to determine factors affecting the emission control performance of the unit.

Factors that may affect SO_2 collection efficiency were an important focus of the process evaluation. It was anticipated that, for example, gas flow to each module might cause efficiency to vary from 85 to 92 percent. Absorber pH, sulfite ion concentration and regenerator flow are other important factors affecting SO_2 efficiency which were considered in the initial test approach.

Emissions parameters which applied to the SO_2 control device included inlet and outlet SO_2 diluent levels. These measurements were conducted at the specified locations on each of the two modules. In addition, the mobile laboratory was equipped to measure the gas flow rate through each module. Measurements related to NO_x included total oxides of nitrogen prior to the scrubber, carbon monoxide as a gauge for combustion upset conditions, excess air measurements prior to the air preheater and diluent measurements at the monitoring points for NO_x.

In addition to the measurements/parameters mentioned above, other process signals available from the plant control panel were logged. These included various scrubber and boiler parameters and initially stack emissions for SO_2/O_2. However, the stack emissions measurements were discarded due to the eratic behavior of this system. All data parameters were logged and processed by an onboard minicomputer.

Utilizing data obtained during the data acquisition phase of the program, GCA conducted a performance evaluation of the NO_x and SO_2 control equipment. Throughout the duration of the data collection phase, a field engineer observed and reviewed the data periodically. At the conclusion of the data collection phase, all data were evaluated to fulfill the objectives of the program.

GENERAL PROGRAM SCHEDULE

The program schedule that resulted is shown in Figure 1. Upon completion of the monitor system startup (M-5), data acquisition and associated quality assurance checks ensued during the period of July 31 through October 8, 1981. Subsequently the engineering assessment was conducted and the final report preparation completed during March of 1982.

FINAL REPORT FORMAT

The final report for this program is contained in five separate volumes which are entitled as follows:

Characterization of the NO_x and SO_2 Control Performances;
Southern Indiana Gas and Electric Co., A. B. Brown Unit No. 1

- Volume I--Program Results
- Volume II--Program Documentation
- Volume III--North Module Sulfur Dioxide Data Reports
- Volume IV --South Module Sulfur Dioxide Data Reports
- Volume V --Oxides of Nitrogen Data Reports

In addition, a summary report has been prepared presenting the results of the program in an abbreviated form.

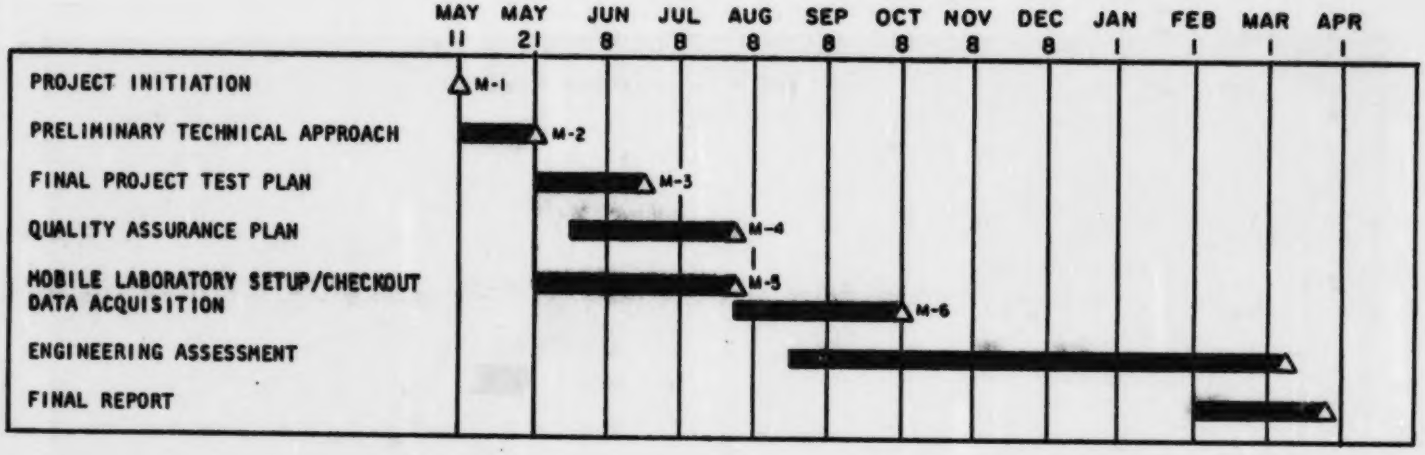
Volume I--Program Results

Volume I discusses the test program approach and the results in detail. Section 2 contains an executive summary; Section 3, a facility description; and Section 4, the technical approach which was utilized to conduct the program. The program results are presented in Sections 5 and 6. Section 5 presents the process evaluation results and Section 6, the measurement system results.

Volume II--Program Documentation

Volume II contains documentation of inputs utilized to obtain the results contained in Volume I. This volume contains the following information:

- Computer program information for obtaining the data tables contained in Volumes III, IV and V and other program data files on magnetic tape.
- Calibration equations used to process the data.



MILESTONE	DESCRIPTION	COMPLETION DATE
M-1	PROJECT INITIATION	05/11/81
M-2	PRELIMINARY TEST APPROACH	05/21/81
M-3	FINAL PROJECT TEST PLAN	06/25/81
M-4	QUALITY ASSURANCE PLAN	07/30/81
M-5	MOBILE LABORATORY SETUP/ CHECKOUT	07/30/81
M-6	DATA ACQUISITION	10/08/81
M-7	ENGINEERING ASSESSMENT	03/15/82
M-8	FINAL REPORT	03/25/82

Figure 1. Realized project schedule.

- Daily three point calibration check data.
- Performance specifications data.
- Boiler and process operating logs (supplied by SIGECO)
- Routine analytical data (supplied by SIGECO)
- Monthly Coal Analyses Reports (supplied by SIGECO)

Volumes III, IV and V--Data Tables

Volumes III, IV and V contain a listing of all data tables generated by the data program mentioned in Volume II. Data tables contained in these volumes include a North Scrubber Summary, a South Scrubber Summary and a NO_x Performance Summary for the following averaging periods:

- 30 day rolling average
- 24 hour average
- 1 hour average
- 15 minute average

Data contained in this volume is also contained on 9-track tape. Utilizing the instructions contained in Section 2 of Volume II, the user will be able to generate the data tables generated during the program.

SECTION 2

EXECUTIVE SUMMARY

Southern Indiana Gas and Electric Company (SIGECO) A. B. Brown No 1 is a modern pulverized coal-fired boiler with an electrical generation capacity of 265 MWE and has been operating since early 1979. The unit is subject to the 1971 Federal New Source Performance Standards (NSPS) which limits SO_2 emissions to 1.2 lb/10^6 Btu (516 ng/J), NO_x emissions to 0.7 lb/10^6 Btu (301 ng/J) and particulate emissions to 0.1 lb/10^6 Btu (43 ng/J).

Emissions of SO_2 are controlled by an FMC concentrated mode dual alkali scrubber system. The three stage two module system was designed to meet the NSPS, when 4.5 percent sulfur coal is burned, by treating all the flue gases at an efficiency of about 85 percent. SIGECO normally burns a 3.5 percent sulfur coal and has, reportedly, been able to meet the standard by treating 90 percent of the flue gas at 90 percent efficiency while bypassing the remaining 10 percent.

The boiler was designed and built by Babcock and Wilcox and includes their dual register burners. Emission tests have demonstrated that these burners limit NO_x emissions to less than 0.5 lb/10^6 Btu (less than 70 percent of the NSPS emissions limitations).

Particulates are removed from the flue gases by a Buell cold side electrostatic precipitator prior to SO_2 removal. Tests conducted with the scrubber off-line indicate that the electrostatic precipitator meets the standard of 0.1 lb/10^6 Btu (43 ng/J). Opacity monitors were installed by SIGECO at the electrostatic precipitator outlets, prior to the scrubbers, for compliance demonstration purposes.

Data obtained from the test program are summarized in the following subsections of Section 2. The data is presented under three separate categories which include emissions control performance, effects of process variables on emission control performance and measurement system results.

EMISSIONS CONTROL PERFORMANCE

NO_x Emissions

The mean NO_x emission rate for the full test program was 163 ng/J (0.38 lb/10^6 Btu). All the hourly readings were below 210 ng/J (0.49 lb/10^6 Btu) which is equivalent to 70 percent of the 1971 NSPS. Daily average emission rates ranged from 135 ng/J (0.3 lb/10^6 Btu) to 219 ng/J (0.51

lb/10^6 Btu). The thirty day rolling averages for NO_x emissions were all below 168 ng/J (0.4 lb/10^6 Btu), ranging from 160 ng/J (0.370) to 167 ng/J (0.388 lb/10^6 Btu) as shown in Table 1.

SO_2 Emissions

Emissions of SO_2 are controlled by two parallel FMC dual-alkali scrubbers. For the purpose of this test program, Southern Indiana Gas and Electric Company operated the FGD system in their customary manner to meet their required regulations. The system was not operated to optimize SO_2 collection efficiency. Valid data were collected for the performance of the north module for 68 days and for the south module for 62 days. The boiler was shut down for 2 days late in the program due to pulverizer problems and the south scrubber module was offline during the first 6 days of the test program as a result of recirculation pump failure.

The mean SO_2 removal efficiency for the north module was 88.0 percent compared to 86.5 percent for the south module. The higher average efficiency for the north module was, in part, attributable to the first 6 days of data collection when the north module averaged 95.2 percent efficiency and the south module was not operating. Table 1 and Figure 2 show the 30 day rolling averages beginning at the thirtieth day. There was a slight declining trend for the rolling averages as the test program proceeded. The north module declined from 90.5 percent to 85.8 during the last 30 day period. The efficiency for the south module declined from 88.0 percent to 85.4 percent at the end of the test program. Decline in the rolling average SO_2 collection efficiency coincides with the reduction in average boiler load which was lower during the end of the test program. As shown by the dotted line in Figure 2, the scrubber system consistently operating above the design guarantee.

Emissions of SO_2 for the north module averaged 344 ng/J (0.80 lb/10^6 Btu) while the south module averaged 391 ng/J (0.91 lb/10^6 Btu). Thirty day rolling averages for the SO_2 emissions are presented in Table 1 and Figure 3. The north tower 30 day rolling average was 288 ng/J (0.65 lb/10^6 Btu) early in the program but after a few days it rose to the 350 to 380 ng/J (0.81 to 0.88 lb/10^6 Btu) range. Thirty day rolling averages for the south tower were in the range of 355 to 418 ng/J (0.81 to 0.98 lb/10^6 Btu). This range of operation constitutes consistant performance at emissions levels of 68 to 82 percent of the design guarantee.

EFFECTS OF PROCESS VARIABLES ON EMISSION CONTROL PERFORMANCE

Various regression techniques were used to investigate possible effects of process variables on emission control performance. Hourly data consisting of up to 1400 hours were used to develop correlationss between process variables and emission control performance as indicated by NO_x emission rates and SO_2 efficiencies from each module.

TABLE 1. UNIT NO. 1 - PERFORMANCE SUMMARY STATISTICS

Averaging Period	Statistical Parameter	Sulfur Emissions (ng/J)		Tower Efficiency		NO_x Emissions
		North	South	North	South	
Hourly	Mean	341	391	88.0	86.5	163
	STD Dev	115	101	4.1	3.4	15.8
	Min	29	102	75.9	71.2	76
	Max	662	887	99.0	96.7	209
Daily	Mean	344	391	88.0	86.5	163
	STD Dev	92	62	3.3	2.2	10.9
	Min	67	216	81.1	82.5	135
	Max	544	600	97.7	92.2	219
30 Day Roling	Mean	341	394	88.4	86.6	163
	STD Dev	35	19	1.6	1.0	2.5
	Min	274	355	85.8	85.3	160
	Max	396	418	90.5	88.0	167

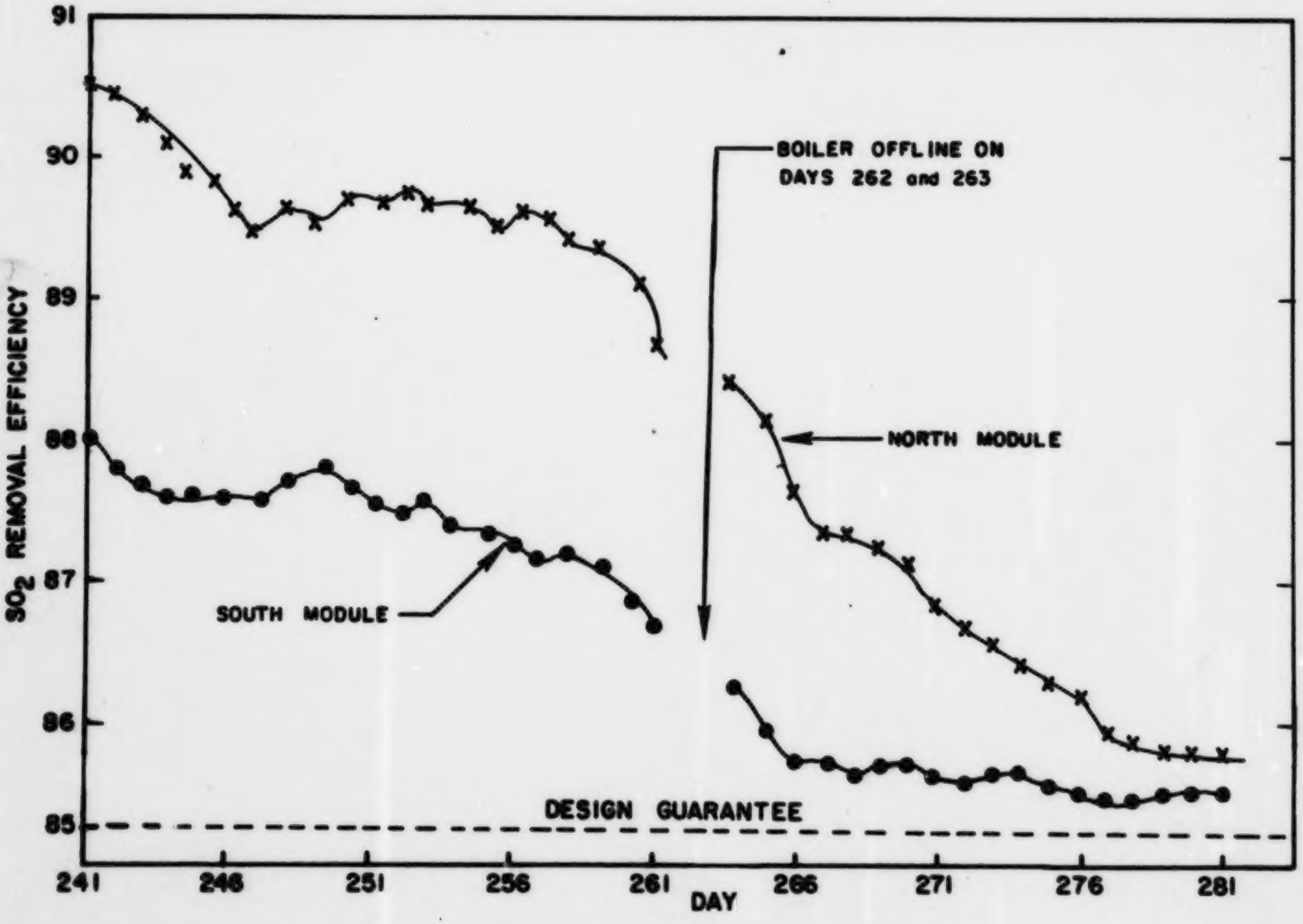


Figure 2. SO_2 efficiency, 30 day rolling average.

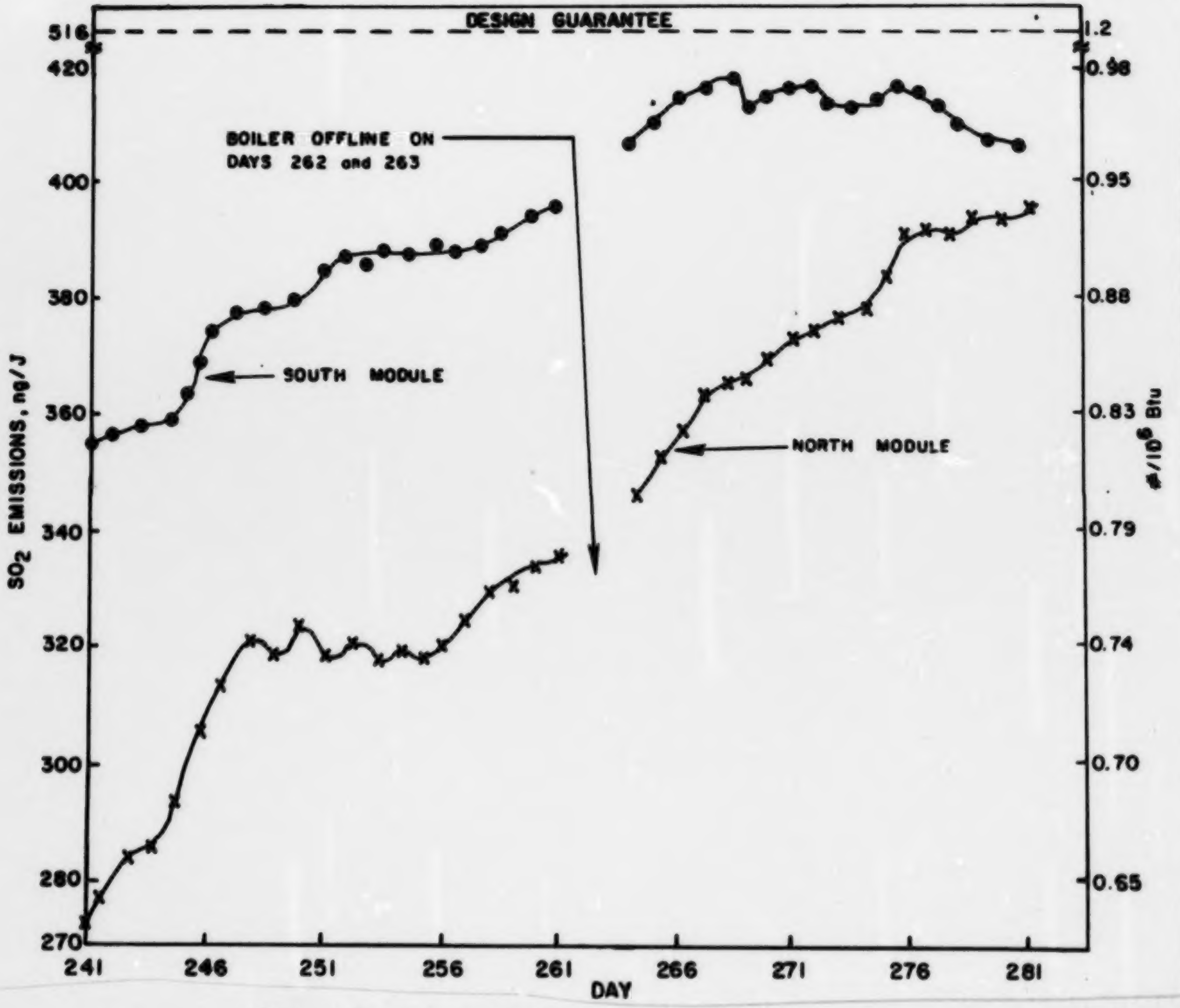


Figure 3. SO_2 emissions, 30 day rolling average.

Oxides of Nitrogen

Emissions of NO_x appeared to be related to the flue gas oxygen concentration as measured at the inlet locations (the north tower inlet value was used), boiler load and carbon monoxide concentration. It was expected that the oxygen concentration in the boiler as indicated by the concentration prior to the air preheater might effect NO_x emissions but this proved to be a very weak correlation.

The equation selected to predict NO_x emissions is:

$$NO_x \text{ (ng/J)} = 27.8 + 12.9 \text{ (}O_2\text{, \%)} + 0.216 \text{ (load, MWE)} - 0.0495 \text{ (CO, ppm)} \qquad (1)$$

This equation explained 52 percent of the variation in NO_x emissions and was highly significant as indicated by the F value of 491. A comparison of the predicted and measured NO_x emissions is presented in Figure 4. If the linear regression explained all the variation in NO_x emission rates, all the points would fall on the indicated 45 degree line. Because the selected equation explains 52 percent of the variation in emissions, the data points are scattered around its 45 degree line.

The linear regression equation developed for the NO_x data collected at A. B. Brown defines a real and statistically significant relationship that was observed in the data base. It does not prove a physical or chemical cause and effect relationship nor should it be applied to data from other sites. Further investigation of the observed relationship between process variables and emissions may be appropriate.

Sulfur Dioxide

The development of correlations between SO_2 removal efficiency and process parameters was approached using Venturi scrubber models as background information. According to these models, the main variable which affects collection efficiency is liquid drop surface area. The surface area is directly proportional to the pressure drop across the venturi as determined by the flue gas velocity. The higher the gas velocity, the smaller the drop size and, consequently, the larger the surface area the atomized liquid will exhibit.

Similarly, FMC's tower design depends on pressure drop (gas velocity) for atomization. Consequently, these towers are expected to exhibit higher collection efficiencies at full load conditions.

Collection efficiencies for both towers were affected by gas flow only as shown by the equations below:

North Module:

$$\text{eff} = 6.4\text{X}10^{-7} \text{ (flow)}^{2.5} - 3.4\text{X}10^{-6} \text{ (flow)}^{3.5} + 4.7\text{X}10^{-9} \text{ (flow)}^{4.5} \qquad (2)$$

$$R^2 = 0.9814 \text{ for } N = 530$$

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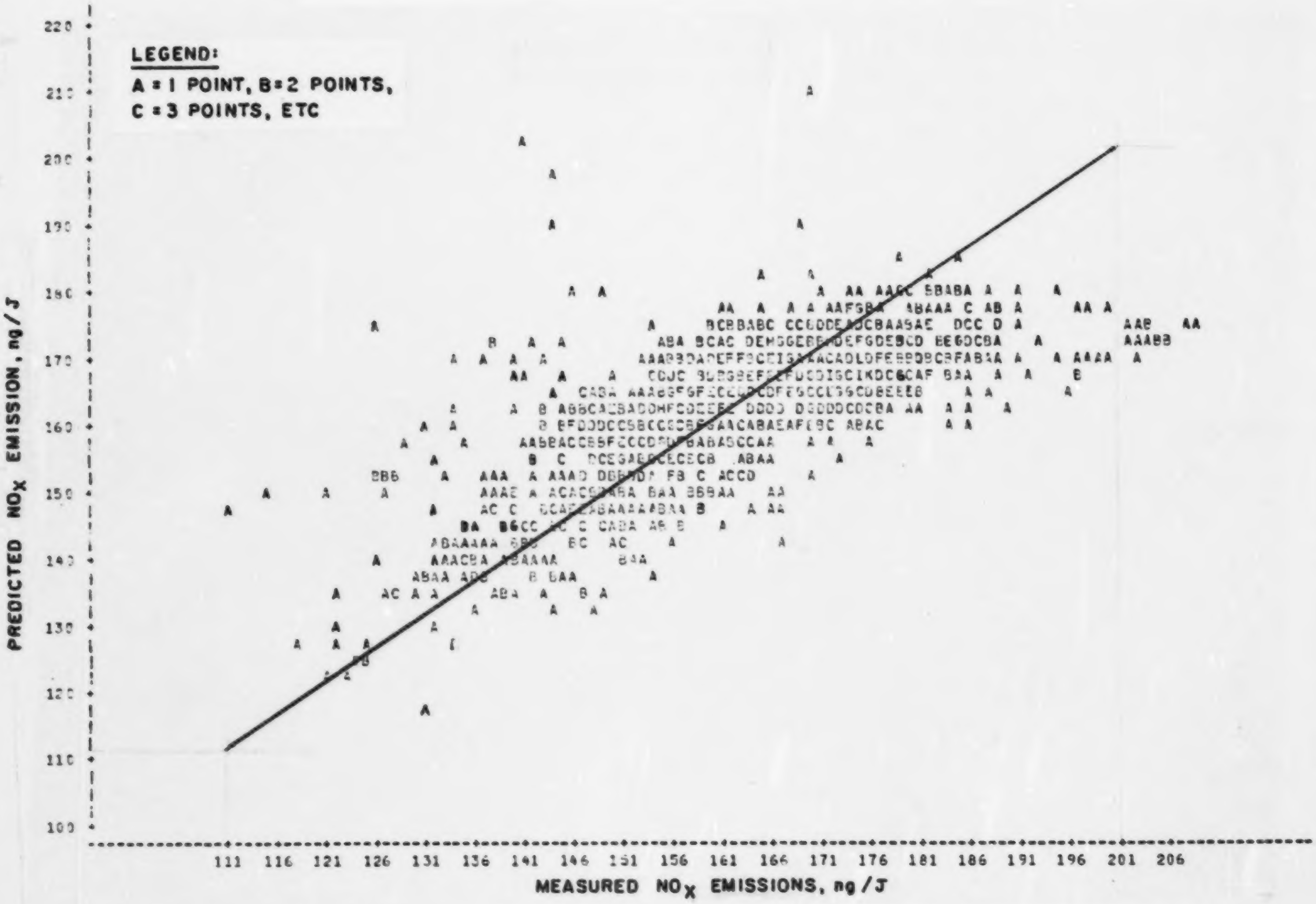


NOTE: 304 OBS HAD MISSING VALUES

Figure 4. Comparison of hourly predicted NO_x and measured NO_x emissions.

South Module:

$$eff = 1X10^{-3}\ (flow)^{2.5} - 6.3X10^{-6}\ (flow)^{3.5} + 1.0X10^{-8}\ (flow)^{4.5} \tag{3}$$

$$R^2 = 0.9280 \text{ for } N = 506$$

where eff is the percent sulfur removal efficiency, %

flow is the gas flow rate at standard conditions, a ft^3/min

R^2 = correlation coefficient

N = number of data points analyzed

These equations describe greater than 92 percent of the process variation for the data segment analyzed. It should be noted, however, that these correlations may only be indicative of the data set obtained from this test site and may not represent performances which may be exhibited by other dual-alkali systems.

As long as the pH of the system is in tolerance, the variation of control performance is only a function of gas flowrate. In the FMC system, the scrubbants are highly buffered and automatically regenerated. In addition, the liquid circulation rate is held constant through the tower and the scrubbants are regenerated automatically as required.

No equations were generated to describe outlet emission performance, since the equations describing efficiency can also be rearranged to describe outlet emission rates.

MEASUREMENT SYSTEM RESULTS

Operational Experience

The mobile emissions laboratory utilized to collect the primary emissions data, initially was anticipated to require a setup and checkout period of approximately 1 month. Subsequently, a week was scheduled for conducting the performance specifications tests which are designed to assess the precision and relative accuracy of the measurement system. Actual setup and commencement of monitoring required an additional 6 weeks for equipment troubleshooting, remedial modifications and subsequent checkout.

The problems most commonly encountered throughout this program involved leakage within the extraction system and a spurious voltage induction problem which caused the baseline of the analytical instrumentation to shift. The latter problem was remedied prior to monitoring. Leakage throughout the system was due to valve diaphram ruptures and the flowing of Teflon sample lines at connection points throughout the system. These problems were alleviated by the remedial modifications presented in more detail in Section 6.

After correcting the system problems, approximately 68 days of data were collected during the period of July 31 through October 8, 1981. During this time, the plant was off line a total of 2 days.

After system startup, very little data loss resulted from hardware failure. Hardware availability during the program approached 98 percent while the data availability rate (including primary and backup data systems) approached 95 percent. Valid data capture was approximately 93 percent for the primary emission parameters, and 70 percent for the associated process measurements. The process data capture rate was significantly lower than the emissions capture rate due to the fact that these signals were not connected to a backup logger and most were often not available from control room log sheets.

During the test program, the mobile laboratory was attended by a full-time operator. On a daily basis, the operator conducted calibration checks, performed routine maintenance, accessed the previous day of data (printouts) and filled out daily maintenance check lists and site logs. The major portion of the day was spent reducing data and performing program related paperwork. All data were processed into a report format by the onsite computer.

Stratification Results

Prior to the initiation of the routine monitoring phase, stratification tests were conducted at each monitoring location. This test sequence was designed to ensure that the probe locations would provide representative flue gas samples. The procedure involves traversing the cross sectional area of the flue gas stream to define the spatial variability of the analyte of interest. This procedure is normally conducted where the probability of stratification is high (e.g., after wet scrubbers). Periodically, the tests were repeated to verify that the representativeness of the flue gas samples remained unchanged.

A summary of the stratification results are shown in Table 2. Data listed in the first two columns were obtained during the initial stratification tests. Based on these initial tests the probes were placed in the geometric center of each monitoring location. Subsequent tests at the outlet locations indicated that the average points of concentration at the outlet locations were unchanged. Further testing was not conducted at the inlet locations due to the low probability of variable stratification.

Performance Specifications Tests

The results of the performance specifications tests are summarized in Tables 3 and 4. Due to a shortage in span gases, the optional 2 hour drift test was not conducted. All analyzers conformed to the 24 hour drift and calibration error criteria, except for the outlet SO_2 analyzer which exceeded the midscale calibration error criterion and the NO_x analyzer which exceeded the calibration drift and the high scale calibration error criteria. Due to these results, the NO_x span gases were analyzed to reverify the "true" concentration; however, the results of the analyses did not alter the performance results.

TABLE 2. A.B. BROWN STRATIFICATION TEST SUMMARY

	Outlets (6/30)		Inlets (7/8)		Outlets (9/17)		Outlets 10/8	
	Full load		Full load		Low load		Low load	
Port	North (ng/J)	South (ng/J)	North (ng/J)	South (ng/J)	North (ng/J)	South (ng/J)	North (ng/J)	South (ng/J)
Mean conc.	512	169	2999	3031	312	381	294	251
S	32	48	103	31	36	31	26	26
Ref/mean	1.00	1.08	1.05	1.0	1.02	1.01	0.89	0.96

Mean: Average of all traverse measurements (ng/J)

S: Standard deviation of all traverse measurements (ng/J)

Ref/mean: Ratio of Measurement at Probe Placement Point to Mean Conc.

TABLE 3. 24-HOUR ZERO AND CALIBRATION DRIFT SUMMARY (A. B. BROWN)

	24-hour drift		Calibration error	
Parameter	Zero[a] (%)	Calibration[a] (%)	Mid (%)	High (%)
Inlet SO_2	0.5	1.1	4.1	0.3
Outlet SO_2	1.6	4.9[b]	9.4[b]	3.6
Inlet O_2	0.1 (O_2)	0.1 (O_2)	1.5	1.5
Outlet O_2	0.1 (O_2)	0.2 (O_2)	1.3	3.4
Inlet NO_x	0.1	3.3[b]	1.6	5.6[b]
Inlet CO	0.9	1.3	3.2	2.5
Outlet CO_2	0.2 (CO_2)	0.3 (CO_2)	1.7	3.8

[a] O_2 and CO_2 results are presented in terms of O_2 and CO_2 concentration and not % of full scale.

[b] Exceeded Performance Specifications Test criteria.

TABLE 4. SUMMARY OF RELATIVE ACCURACY TEST RESULTS FOR A. B. BROWN 1

Parameter	North Tower (% RA or % CO_2/O_2)						South Tower (% RA or % CO_2/O_2)					
	Inlet			Outlet			Inlet			Outlet		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
SO_2	16.9	5.5	21.4	16.4	14.6	13.5	28.7	12.5	14.7	14.8	14.7	18.4
O_2	0.46	0.30	1.10	0.13	1.14	0.55	0.53	0.14	1.09	0.40	0.62	1.33
CO_2	---	---	---	0.81	2.29	1.17	---	---	---	1.98	0.97	1.14
NO_x	23.9	29.0	26.5	---	---	---	a	a	a	---	---	---
$E_{SO_2}(O_2F)$[b]	17.3	6.1	13.6	17.0	12.9	14.1	28.6[d]	12.5	12.8	11.8	14.2	14.4
$E_{SO_2}(CO_2F)$[c]	---	---	---	21.0[d]	27.9[d]	8.7	---	---	---	16.1	12.8	19.2
$E_{NO}(O_2F)$	36.6[d]	31.0[d]	23.9[d]	---	---	---	a	a	a	---	---	---

[a] Test runs invalidated.

[b] Relative accuracy based on O_2 "F" factor emission rate.

[c] Relative accuracy based on CO_2 "F" factor emission rate.

[d] Exceeds 20 percent relative accuracy based on emission rate.

---Not applicable.

The results of the relative accuracy testing are shown in Table 4. Generally speaking, the results were favorable and, except for the NO_x results, were less than the stated compliance limit of 20.0 percent. The results for the NO_x analyzer were 30 percent in terms of emission rate. This high value for relative accuracy is the result of a large confidence interval and not an absolute bias. This denotes random scatter when comparing the differences between the reference method and the analyzer.

Emission rates for SO_2 were calculated using both the O_2 based and CO_2 based "F" factors. As shown by the results, the different methods for calculating the emission rate did not yield comparable relative accuracy results. This discrepancy may be a result of the high CO_2 Relative Accuracy (e.g. 0.8 percent CO_2) and the opposite relative bias for the O_2 and CO_2 analyzers.

Monitoring System Precision and Accuracy

Individual instrument precision and accuracy estimates were determined according to the proposed Quality Assurance Regulations, soon to be promulgated as 40 CFR 60, Appendix F. These precision estimates were determined by GCA utilizing the daily zero and span data, and the accuracy of each instrument was assessed by an independent auditor.

Results for instrument precision and accuracy were listed as satisfactory. Precision estimates for the total data collection period appear satisfactory and the results of the performance audit were "acceptable" as defined by the auditors.

SECTION 3

TEST FACILITY DESCRIPTION

A. B. Brown No. 1 is a modern pulverized-coal-fired boiler with an electrical generation capacity of 265 MWe and has been operating since the spring of 1979. The unit is subject to the 1971 Federal New Source Performance Standards (NSPS) which limits SO_2 emissions to 1.2 lb/10^6 Btu (516 ng/J), NO_x emissions to 0.7 lb/10^6 Btu (301 ng/J), and particulate emissions to 0.1/10^6 Btu (43 ng/J). Table 5 lists the general specifications for the unit. Gases exiting the boiler are split into two independent gas flow streams and ducted through two parallel air preheaters, parallel precipitator modules and parallel scrubber towers as shown in Figure 5. The exhaust gases are then emitted through a 500-foot stack.

TABLE 5. GENERAL UNIT SPECIFICATIONS (A. B. BROWN NO. 1)

Boiler:	Babcock and Wilcox Opposed-Fired Boiler 265 MWE gross capacity Low NO_x (dual register) burners	
Fuel:	Bituminous coal	
	Average sulfur:	3.5%
	Average ash:	15%
	Average chloride:	0.05%
	Heating value:	11,000 Btu/lb
	Uncontrolled SO_2	Approx. 6.5-7.0 lb/10^6 Btu
Particulate Control:	Buell cold side electrostatic precipitator--dual parallel modules	
Sulfur Control:	FMC concentrated-mode dual-alkali scrubber system--dual parallel modules	
Reheat Type:	Flue gas bypass	

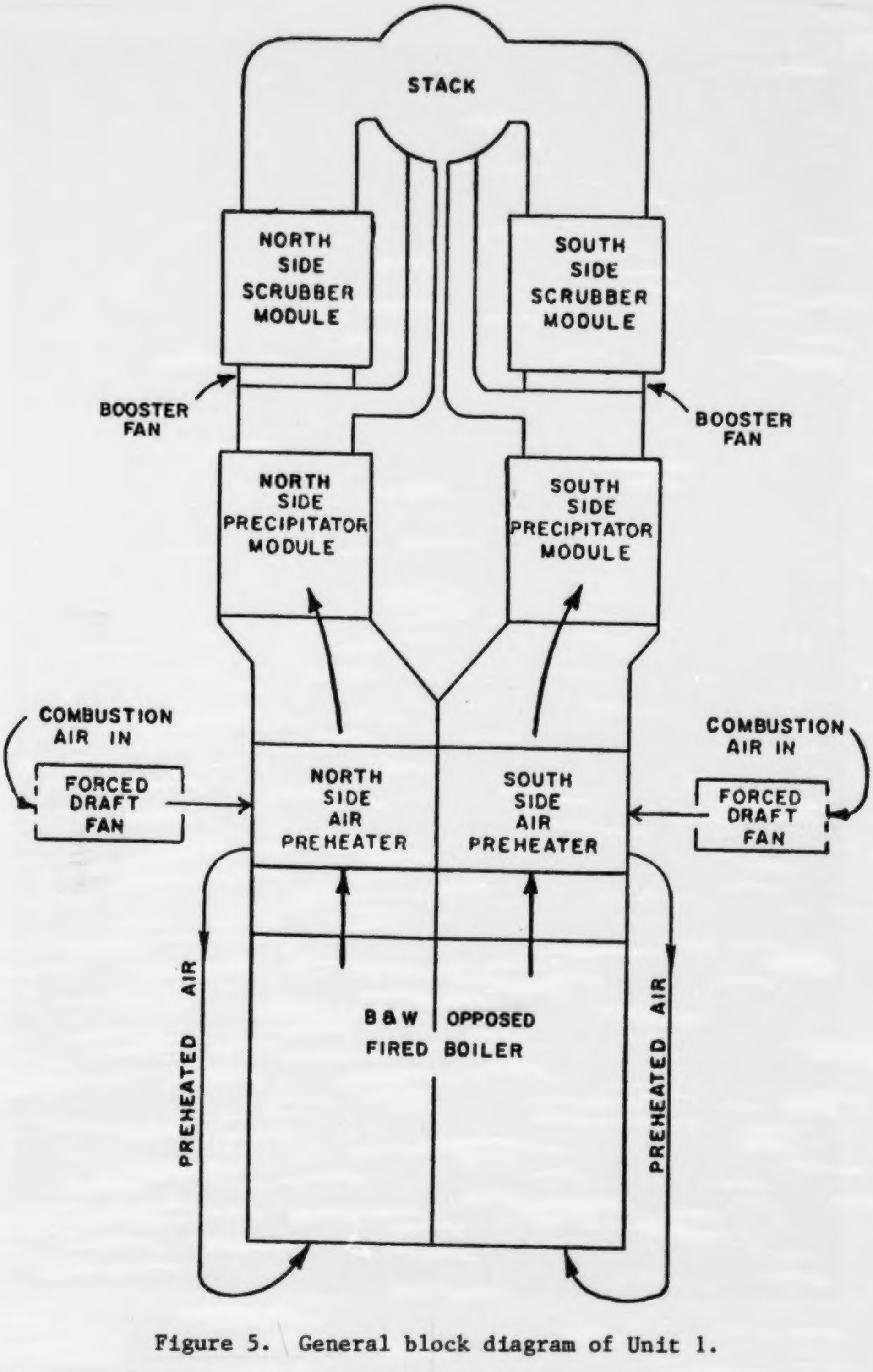

STACK
NORTH SIDE SCRUBBER MODULE
SOUTH SIDE SCRUBBER MODULE
BOOSTER FAN
BOOSTER FAN
NORTH SIDE PRECIPITATOR MODULE
SOUTH SIDE PRECIPITATOR MODULE
COMBUSTION AIR IN
COMBUSTION AIR IN
FORCED DRAFT FAN
FORCED DRAFT FAN
NORTH SIDE AIR PREHEATER
SOUTH SIDE AIR PREHEATER
PREHEATED AIR
PREHEATED AIR
B&W OPPOSED FIRED BOILER

Figure 5. General block diagram of Unit 1.

For the purpose of this program, all sampling and monitoring activities were conducted around the scrubber superstructure as shown in Figure 6. Shown on this figure are the sampling sites at which the pollutant measurements were made. In addition, several process measurements were conducted at the scrubber outlet locations. For the SO_2 performance evaluation, SO_2 and O_2 were measured at the inlet and outlet locations of each scrubber module. Gas flow rate and CO_2 were continuously measured only at the outlets. Opacity was measured at the scrubber inlets to ascertain when precipitator upset conditions existed. Data for the NO_x evaluation included NO_x, CO, O_2, and boiler excess air measurements at the inlets to each module.

OXIDES OF NITROGEN CONTROL SYSTEM

Boiler Description

A. B. Brown No. 1 is a pulverized coal-fired unit with gross and net electrical capacities of 265 and 250 MW, respectively. Steam is produced by a single boiler supplied by Babcock and Wilcox. The boiler was put into commercial service in 1979.

Design flue gas flow from the boiler is 910,000 acfm at 310°F and 4 percent O_2. Excess air at 4 percent O_2 is about 24 percent. Dual register burners are mounted on opposite walls of the furnace for limiting NO_x formation.

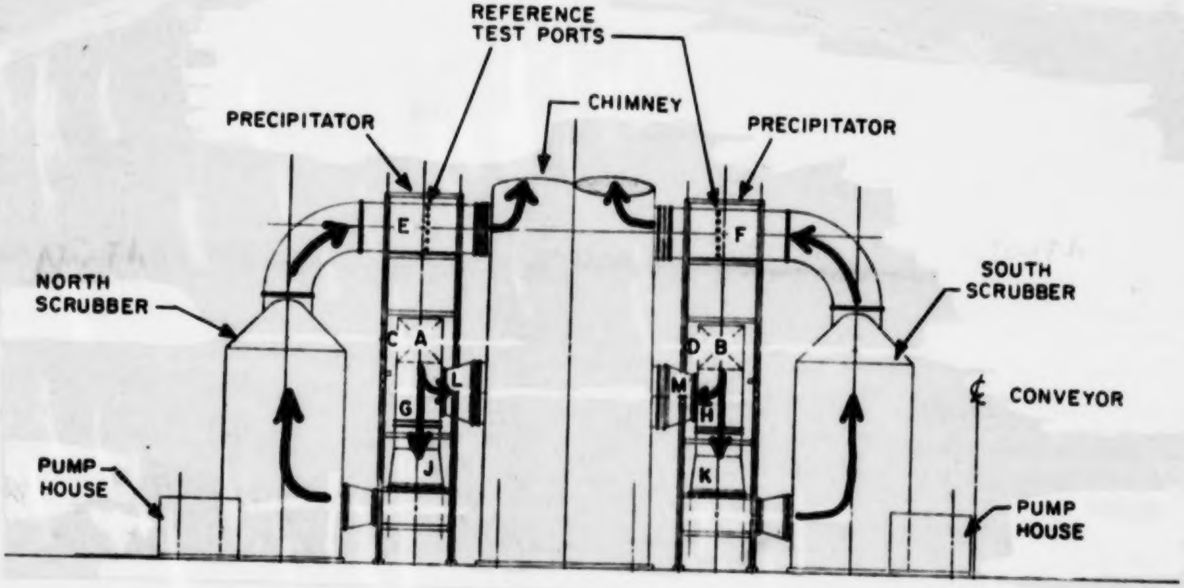
Fuel Characterization

Bituminous coal burned at A. B. Brown has a sulfur content near 3.5 percent. It is a low chloride coal, usually containing about 0.05 percent chloride with a heating value of approximately 11,500 Btu/lb.

Coal is received twice a week by train to meet the 120 ton/hr demand at full load. Assuming an annual load factor of 70 percent, the unit would use 730,000 tons of coal per year. Two samples are obtained from each train load, primarily for analysis of sulfur and heating value. Once a week SIGECO obtains and analyzes a sample from the belt feeder. Samples are sent twice a month to an outside laboratory for a more detailed analysis. Table 6 contains a summary of the fuel data from analyses conducted during the test program. These samples were collected by SIGECO as described above. Sulfur varied from a low of 1.88 percent to a high of 4.13 percent. The average sulfur value was 3.22 percent.

Dual Register Burners

B&W has developed the dual register burner shown in Figure 7 to meet NO_x emission standards.[1] The burner limits NO_x formation to acceptable levels, by utilizing a relatively long, narrow flame. The initial burning in the center of the flame is in a fuel rich mixture. Turbulence is kept low to limit the degree of the fuel/air mixing to that which is required to sustain combustion. The remaining air needed to complete combustion is admitted through a separate chamber to totally surround the inner combustion zone. The


REFERENCE TEST PORTS
PRECIPITATOR
CHIMNEY
PRECIPITATOR
E
F
NORTH SCRUBBER
SOUTH SCRUBBER
C
A
D
B
L
M
G
H
℄ CONVEYOR
J
K
PUMP HOUSE
PUMP HOUSE

A. EFFLUENT FROM NORTH SIDE PRECIPITATOR MODULE.
B. EFFLUENT FROM SOUTH SIDE PRECIPITATOR MODULE.
C. NORTH SCRUBBER INLET MONITORING LOCATION (DUCT DIMENSIONS: 12' x 12').
D. SOUTH SCRUBBER INLET MONITORING LOCATION (DUCT DIMENSIONS: 12' x 12').
E. NORTH SCRUBBER OUTLET MONITORING LOCATION (DUCT DIAMETER: 8' x 12').
F. SOUTH SCRUBBER OUTLET MONITORING LOCATION (DUCT DIAMETER: 8' x 12').
G. NORTH SIDE SCRUBBER ISOLATION DOOR.
H. SOUTH SIDE SCRUBBER ISOLATION DOOR.
J. NORTH SIDE SCRUBBER INLET LOUVERED DAMPER.
K. SOUTH SIDE SCRUBBER INLET LOUVERED DAMPER.
L. NORTH SIDE BYPASS DUCT TO STACK.
M. SOUTH SIDE BYPASS DUCT TO STACK.

Figure 6. End view of scrubber arrangement looking west.

TABLE 6. FUEL ANALYSES

Date	Moisture (percent)	Ash (percent)	Sulfur (percent)	Heating value (Btu/lb)	Potential SO_2 emissions (ng/J)[a]
8/5	12.0	9.0	2.82	11,386	2,020
	11.9	8.7	3.53	11,325	2,550
8/12	9.6	9.3	4.13	11,666	2,890
8/19	14.0	12.7	2.71	12,662	1,750
	12.8	8.7	3.49	11,137	2,560
8/26	10.6	8.7	3.45	11,682	2,410
	8.2	8.6	4.05	11,994	2,760
9/2	9.8	8.0	2.72	11,597	1,920
	10.3	9.1	3.85	11,514	2,730
9/9	9.4	9.7	3.42	11,865	2,350
	11.5	8.5	3.93	11,509	2,790
9/16	11.0	8.9	1.88	11,728	1,310
	11.8	8.9	3.68	11,379	2,640
9/23	13.2	10.6	2.17	11,483	1,540
	12.2	8.8	3.51	11,423	2,510
9/30	10.0	10.5	2.62	12,039	1,780
	9.9	8.2	3.56	11,778	2,470
10/7	10.1	8.6	3.77	11,710	2,630
10/14	6.6	8.9	3.04	12,019	2,070
	10.6	5.8	2.02	11,841	1,390

[a] Assumes that 5 percent of the sulfur is retained in the ash.

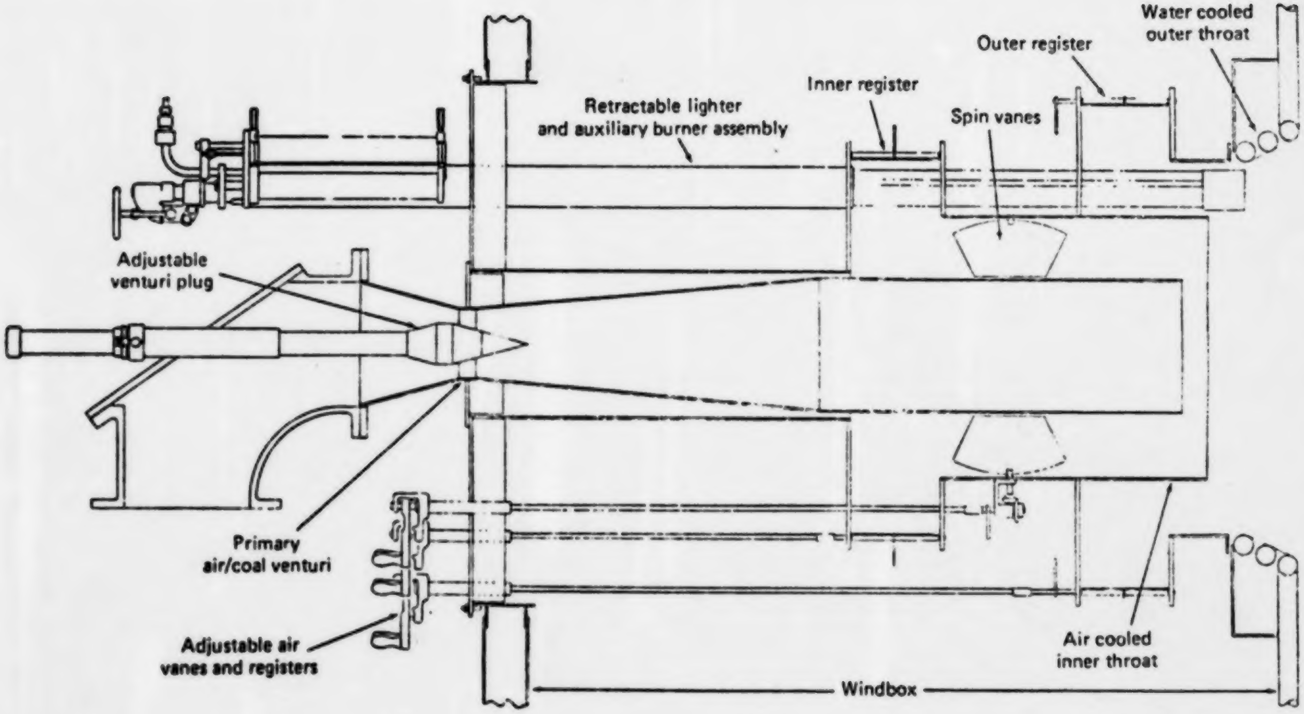

Water cooled outer throat
Outer register
Inner register
Spin vanes
Retractable lighter and auxiliary burner assembly
Adjustable venturi plug
Primary air/coal venturi
Adjustable air vanes and registers
Air cooled inner throat
Windbox

Figure 7. Dual register burner.[1]

7

resulting slow but efficient combustion spreads heat evenly throughout the furnace, lowering flame temperature and reducing NO_x formation.

Secondary air, flowing through the inner register and inner chamber as shown in Figure 7, mixes with the primary air/coal mixture and forms the inner combustion zone. A fuel rich mixture is maintained in this area to limit NO_x formation. Spin vanes, located in the inner chamber, are positioned to provide only enough turbulence to the inner air to establish an ignition zone and maintain stable combustion. With proper register and vane positions and the proper coal to secondary air ratio, ignition of the fuel should occur within a few inches of the top of the coal nozzle. Tertiary air admitted through the outer chamber flows completely around the inner combustion zone and mixes in the furnace with the coal not burned in the inner zone, completing combustion and spreading the heat release from the combustion process over a wide area wall surface.

Vane positions, the position of the venturi plug, secondary air opening and tertiary air openings were set by B&W, during the early operation of the unit, to achieve NO_x emissions below 0.5 lb/10^6 Btu. The positions have never been changed since originally set. The unit was taken offline for 4 to 6 weeks during March and April 1981, after 2 years of operation. Required maintenance and a turbine overhaul were performed. No modifications or adjustments were made to the dual register burners.

Process Instrumentation

Only a few of the boiler instruments are pertinent to the objectives of the NO_x evaluation program. Gross and net boiler output (MW) indicate the fuel input rate. Oxygen content before the air preheater was used to indicate excess air in the boiler.

Because NO_x emissions below 0.5 lb/10^6 Btu have been demonstrated at A. B. Brown No. 1, SIGECO is not required to and does not monitor NO_x emissions. Data on the effect of load on NO_x emissions were therefore not available. In addition the effects of some operations such as burners out of service (as occurs when one or more pulverizers are unavailable) are not known.

PARTICULATE CONTROL SYSTEM

Particulate emissions are controlled by a Buell Envirotech cold side electrostatic precipitator. As shown in Figure 5, the system consists of two parallel modules. The ESP was designed to meet the NSPS of 0.1 lb/10^6 Btu (43 ng/J) by collecting particulate at an efficiency of 99.5 percent.

Prior to the test program, SIGECO installed an opacity monitor at the outlet from each precipitator module. Opacity averaged less than 20 percent during the test program.

SULFUR DIOXIDE CONTROL SYSTEM

Process Description

A simplified flow diagram of the FMC concentrated mode dual alkali system is presented in Figure 8.[2] Sulfur dioxide is absorbed in two parallel towers, by reacting with sulfite ions to form bisulfite according to:

$$SO_2 + Na_2SO_3 + H_2O \rightleftharpoons 2NaHSO_3 \qquad (4)$$

Other cations follow similar chemical reactions. Some SO_2 is also collected by reaction with sodium carbonate (added to the absorber as makeup for sodium losses in the filter cake and elsewhere) according to:

$$Na_2CO_3 + SO_2 \rightleftharpoons Na_2SO_3 + CO_2 \qquad (5)$$

The sulfite solution circulates through the absorber while a bleed stream is withdrawn for regeneration. At a pH of 6.5 the circulating solution (and the bleed stream) contain approximately equal molar concentrations of sulfite and bisulfite ions. Lime is used to regenerate the sulfite ions according to:

$$Ca(OH)_2 + NaHSO_3 \rightleftharpoons CaSO_3 + Na_2SO_3 + H_2O \qquad (6)$$

In the FMC process, sufficient lime is added to achieve a pH of 8.5 converting all the bisulfite to sulfite.

Calcium sulfite, formed in the reaction tank, settles from the slurry in the thickener tank. Some sulfate is formed in the scrubbing system, by oxidation of sulfite, and is partially removed as part of the waste cake. The underflow from the thickener is filtered and washed to recover sodium. The untreated filter cake is transported by truck to an onsite landfill.

The overflow from the thickener is essentially a sulfite solution containing very little if any bisulfite. This solution is pumped to the absorber sump for reuse.

Inputs to the system consists of water, sodium carbonate, and lime. The dual alkali system should operate with a net consumption of water, primarily to make up for water losses in the stack gases. One of the design goals of dual alkali systems is to limit sodium consumption. Sodium in the filter cake is expected to be the major source of losses, but entrainment in the flue gas and spills can also cause losses. Calcium consumption for dual alkali systems, such as that of A. B. Brown, can be expected to be less than 1.01 times the stoichiometric amount.

Typically the pH of the bleed stream is automatically controlled at 6.5. As an example, assume that the amount of SO_2 being collected by the scrubber starts to increase (perhaps because the boiler load increases or the inlet SO_2 concentration increases, or the amount of bypass is decreased by the operator). Increased collection of SO_2 will increase the bisulfite concentration and decrease the sulfite concentration in the bleed stream thus decreasing the bleed stream pH. The automatic pH controller will increase the

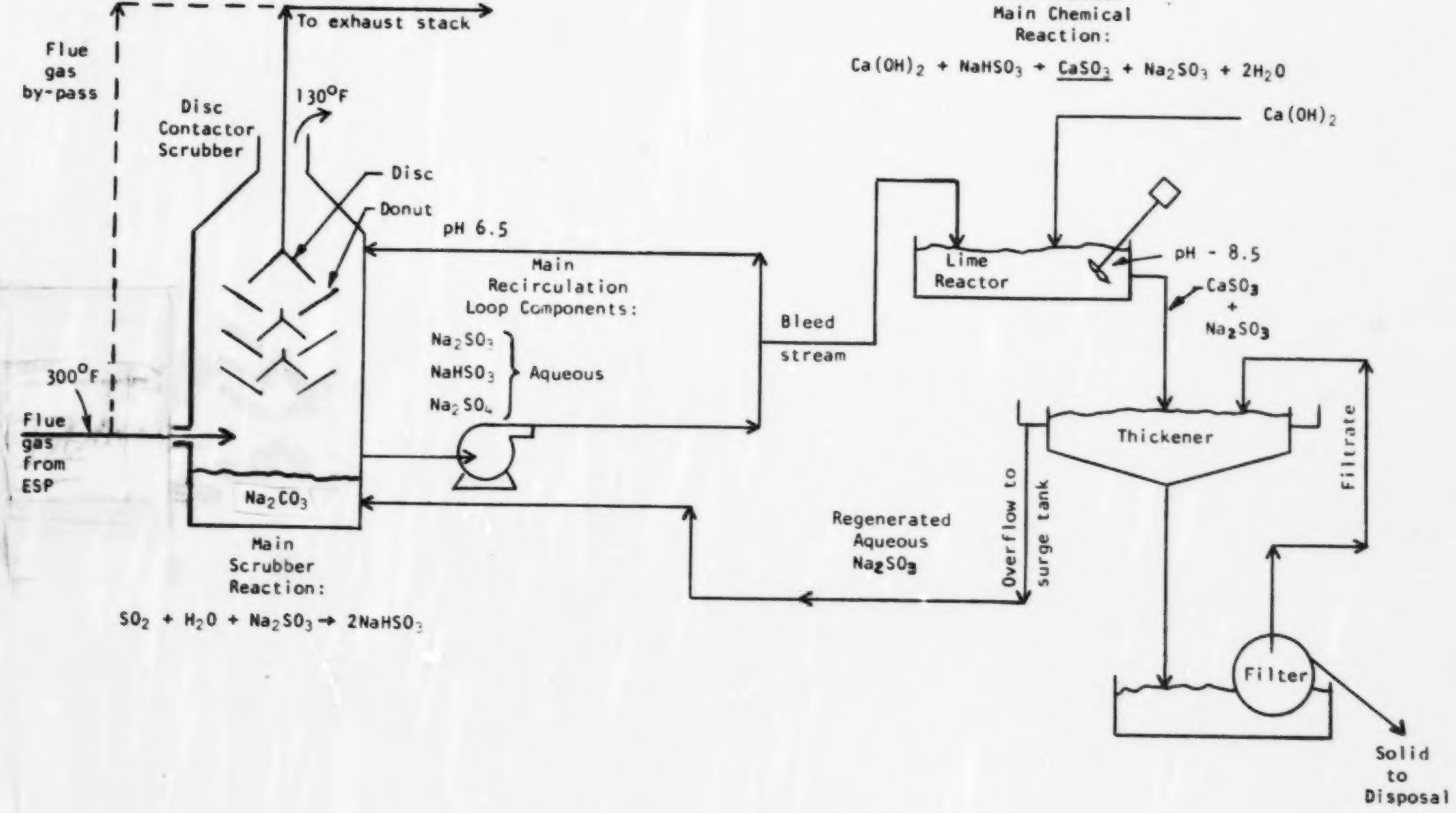

Flue gas by-pass
To exhaust stack
Disc Contactor Scrubber
130°F
Disc
Donut
pH 6.5
300°F
Flue gas from ESP
Na_2CO_3
Main Scrubber Reaction:
$SO_2 + H_2O + Na_2SO_3 \rightarrow 2NaHSO_3$
Main Recirculation Loop Components:
Na_2SO_3
$NaHSO_3$
Na_2SO_4
Aqueous
Bleed stream
Lime Reactor Main Chemical Reaction:
$Ca(OH)_2 + NaHSO_3 \rightarrow \underline{CaSO_3} + Na_2SO_3 + 2H_2O$
$Ca(OH)_2$
Lime Reactor
pH - 8.5
$CaSO_3$ + Na_2SO_3
Thickener
Filtrate
Overflow to surge tank
Regenerated Aqueous Na_2SO_3
Filter
Solid to Disposal

Figure 8. FMC Corporation's concentrated double alkali simplified process flow diagram.

flow of the regenerated solution to the scrubber thus providing more sulfite to handle the increased SO_2 loading. The increased sulfite feed will tend to bring the sulfite to bisulfite ratio in the bleed stream back to one, and thus the pH back to the correct value. As the regenerated liquor feed rate increases, the liquid level in the absorber sump would tend to increase but a level controller will increase the bleed stream flow to maintain the correct level. A pH controller on the lime reactor will increase lime flow to maintain the 8.5 pH, thus completely regenerating the sulfite ion strength.

System Specifications

A schematic of the FMC dual alkali equipment as installed at A. B. Brown is presented in Figure 9. There are two absorbers operating in parallel and a single sulfite regeneration system (lime reactor, thickener, filters and surge tank).

The absorbers are three stage disc contact devices developed by FMC. Design specifications required an efficiency of 85 percent at the highest anticipated inlet sulfur loading (4.5 percent sulfur coal). Under these conditions all the flue gases would be treated to achieve an emission rate of 1.2 lb/10^6 Btu (516 ng/J). Each absorber is also designed to handle up to 60 percent of the boiler load. Guillotine dampers allow SIGECO to isolate one absorber while operating the other. Louver dampers at the inlet to each booster fan provide for gas flow control. Each booster fan is capable of providing 504,000 acfm at 7 inches of water pressure.[3]

The physical dimensions of the absorbers are shown in Figure 6 (previously presented). Each absorber is 30 feet in diameter and 72 feet high to the outlet duct. The bottom 7 feet of the absorber is a reservoir for the recirculation liquor. A single stage thermoplastic Chevron mist eliminator was installed toward the top of the tower. This mist eliminator was replaced with a Euroform mist eliminator supplied by Munters Corporation prior to the test program. Superficial gas velocity is about 10 ft/sec at the normal inlet design gas flow rate of 400,000 acfm. The recirculation liquid to gas ratio is about 10 gal/1000 ft^3.[3]

The lime reactor is a low residence time (approximately 10 minutes) stirred tank that is agitated by a vertically mounted top entry turbine agitator. Lime is fed to the reactor from two paste type slakers each capable of feeding approximately 11,000 lb/hr of a 20 percent $Ca(OH)_2$ slurry.[3]

The thickener is 100 feet in diameter and 16 feet deep. It is gravity fed from the lime reactor and is designed to produce a 20 percent insoluble underflow from the 2 percent insoluble feed. The liquid volume in the tank is about 700,000 gal which provides a residence time of approximately 4 hours at maximum regenerated liquor flow.[4]

Regenerated liquor overflows from the thickener to a 3000 gallon surge tank. A level control system adds water to the surge tank to maintain system water balance. A centrifugal pump transfers regenerated liquor to the absorbers.

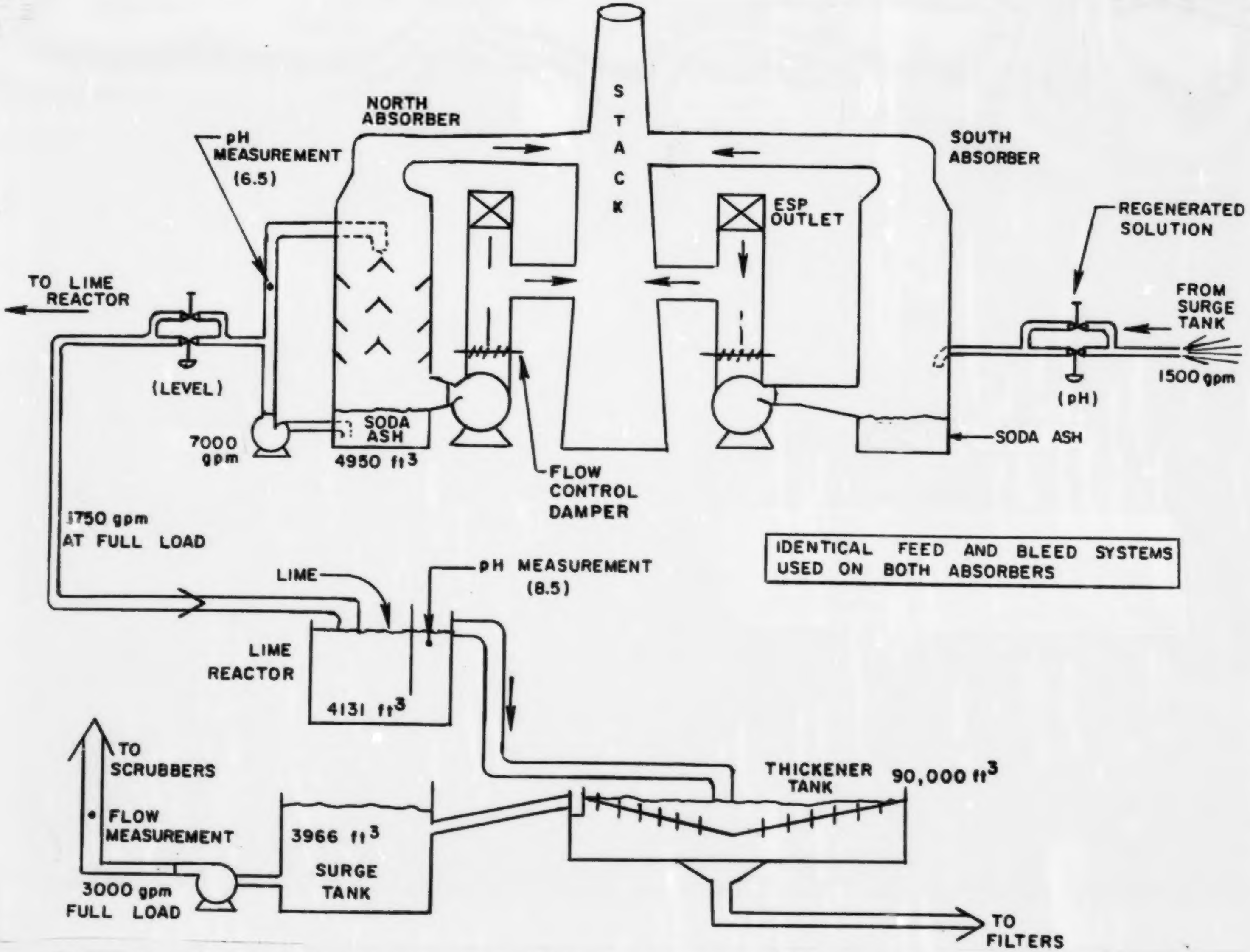

NORTH ABSORBER
S T A C K
SOUTH ABSORBER
pH MEASUREMENT (6.5)
ESP OUTLET
REGENERATED SOLUTION
TO LIME REACTOR
FROM SURGE TANK
(LEVEL)
1500 gpm
(pH)
7000 gpm
SODA ASH
4950 ft³
SODA ASH
FLOW CONTROL DAMPER
1750 gpm AT FULL LOAD
IDENTICAL FEED AND BLEED SYSTEMS USED ON BOTH ABSORBERS
LIME
pH MEASUREMENT (8.5)
LIME REACTOR
4131 ft³
TO SCRUBBERS
FLOW MEASUREMENT
THICKENER TANK
90,000 ft³
3966 ft³
SURGE TANK
3000 gpm FULL LOAD
TO FILTERS

Figure 9. Process schematic of FMC dual alkali process installed at A.B. Brown No. 1.

Thickener underflow is pumped to three rotary filters each sized to handle one-third of the sludge when 4.5 percent sulfur coal is burned. At lower coal sulfur contents the filters have some excess capacity. A vacuum pump for each filter provides 20 inches of mercury vacuum at a flow of 1450 acfm. The cake is washed with water to recover sodium. Cake is discharged directly to dump trucks by knife type cake removal devices. The sludge is landfilled onsite without treatment.

Process Surveillance

Process Instrumentation--

Instruments used in operating the SO_2 scrubbing system are listed in Table 7. The purpose of each measurement, as it relates to the SO_2 scrubbing process, is also included in the Table. SIGECO's use of these instruments is described in more detail in the subsection entitled "SIGECO Operating Procedures" which follows the discussion of chemical analyses. Several instrument measurements not included in the system or not currently operating are worth mentioning. First there is no indication of the regenerated liquor flow to each absorber. This flow is controlled by the pH monitor and may vary between the North and South absorbers. Gas flow to each of the absorbers is varied from hour to hour by adjustment of dampers but there was no indication of the actual flow to each absorber. For this test program, GCA installed monitors for measuring the gas flow rate exiting each tower. Flow meters exist on the recirculating liquor lines but have never been calibrated or used. There are currently no measurements of absorber or mist eliminator pressure drop. The mist-eliminator pressure drop measurement was used in the past but was not operational during the test program.

Chemical Analyses--

SIGECO conducts scheduled chemical analyses on a two shift per day basis during the week and one shift per day on weekends. In addition, unscheduled analyses are conducted in response to requests from operating personnel. The schedule and types of analyses have been varied in response to system operating requirements. The frequency and type of analyses conducted on the scrubber solution and regenerated liquor are presented in Table 8. Because the continuous pH monitor measuring the scrubber bleed stream (1) controls the process, (2) is an essential data point in SIGECO's method of determining compliance with the SO_2 standard, and (3) is subject to drift, SIGECO laboratory personnel check, clean and recalibrate the monitor three times per day during the week and once per day on the weekends. In addition, it is not unusual for the operator to ask for unscheduled checks of the continuous pH monitors.

A second important parameter is the sulfite ion concentration in the regenerated liquor. This parameter is also used in SIGECO's material balance method of determining compliance with the SO_2 emission standard. If the continuous SO_2 monitor was working properly, the sulfite ion concentration would not be as important, as long as it did not drop too far below the design value. The concentration of sulfite in the regenerated liquor should change very slowly. The thickener holds approximately 700,000 gallons compared to the maximum input and output flow of only 3,500 gal/min. Even if the feed to the thickener is not regenerated, the output from the thickener will change slowly and still provide adequate sulfite ion concentration for several hours.

TABLE 7. INSTRUMENTS USED BY SIGECO TO CONTROL OR MONITOR THE SO_2 SCRUBBING SYSTEM

Instrument	Purpose
Gross electrical generation	Used with coal analysis to calculate required SO_2 removal (mole/hr).
Total regenerated liquor flow	Used with $SO_3^=$ analysis to indicate $SO_3^=$ feed to tower (mole/hr).
Bleed pH - North module	Controls regenerated liquor feed to North module.
Bleed pH - South module	Controls regenerated liquor feed to South module.
Lime reactor pH	Controls lime addition rate to complete conversion of HSO_3^- to $SO_3^=$.
Soda ash control valve - North module	Controls soda ash addition rate to North module.
Soda ash control valve - South module	Controls soda ash addition rate to South module.
Opacity - North module inlet	Required by EPA for particulate compliance purposes.
Opacity - South module inlet	Required by EPA for particulate compliance purposes.
Stack	Temperatures can be used to a limited extent to indicate amount of bypass.
Soda ash tank temperature	Temperature must be maintained high enough to prevent solidification.
Scrubber liquid level	Controls scrubber bleed flow.
Sulfur dioxide and oxygen monitors	Used to determine compliance with SO_2 emission standards when operating.

TABLE 8. CHEMICAL ANALYSES--FREQUENCY AND TYPE

Type of analysis	North scrubber Weekdays	 Weekends	South scrubber Weekdays	 Weekends	Regenerated liquor[a] Weekdays	 Weekends
Specific gravity	1	1	1	1	1	1
pH - local	3	1	3	1	0	0
pH - laboratory	3	1	3	1	3	2
HSO_3^-	1	1	1	1	1	1
$SO_3^=$	1	1	1	1	3	2
SO_4	0	0	0	0	1	1
Chloride	0	0	0	0	0	1[b]

[a] Thickener overflow.

[b] Once per week.

In addition, SIGECO periodically conducts filter cake analyses. Prior to the test program samples were collected once per day, during the week and sent to National Laboratories for analyses. Results are received about 10 days after sample collection. The samples were analyzed for moisture, solubles, sodium and chloride, and of sulfur.

Factors Affecting SO_2 Performance

Gas Velocity--

Many scrubbers use spray nozzles to atomize the scrubbing solution. If the liquid flow is constant, the efficiency of these spray tower scrubbers decreases as the gas flow increases. In contrast, the FMC design application at A.B. Brown uses gas velocity in conjunction with the discs in the tower to atomize the scrubbing solution and provide good gas liquid contact. The efficiency of the FMC design should increase as the gas flow increases (liquid flow is constant) rather than decrease as in the case for spray towers. Discussions with FMC indicate that at the full load design gas velocity, an efficiency of 92 percent can be expected. However at the minimum boiler load of 100 MW, efficiencies may be in the range of 80 to 85 percent. To evaluate the effect of gas velocity on efficiency, GCA augmented the available process data by measuring the gas flow to each module. A.B. Brown, or a larger boiler with more modules, could maintain high velocities (and efficiencies) through the absorber by taking one or more modules off-line during low load operation. To date SIGECO has had no need to operate in this mode.

pH--

The importance of pH to GCA's process evaluation was less clear. The FMC patented pH range of chemistry is 6 to 7 in the absorption section. At pH levels below 6 the vapor pressure increases, however, since A. B. Brown is a high sulfur coal application even collection efficiencies greater than 90 percent would not be expected to run into vapor pressure limitations. At pH's above 7 carbonate absorption, which is undesirable, comes into play,. The dual alkali system at A. B. Brown runs nominally at a pH of 6.5. At this point the concentrations of sodium sulfite and bisulfite are roughly equal resulting in a high buffering capacity. This buffering combined with the fact that the concentration of sulfite being circulated is several times that necessary to absorb the SO_2 results in a small dependence of collection efficiency on absorber pH for A. B. Brown's conditions.

$SO_3^=$ Concentration--

Sulfite ion concentration in the regenerated liquor feed and the regenerated liquor flow rate can be an important variable. The concentration and flow must be high enough to provide adequate $SO_3^=$ to react with the SO_2. The adequacy of the $SO_3^=$ feed rate is reflected in the bleed pH; if the amount of $SO_3^=$ is inadequate the pH will fall. In addition the $SO_3^=$ concentration may affect scrubbing efficiency. Extremely low concentrations can be expected to produce lower SO_2 efficiencies. Whether this effect will be observed within the normal sulfite concentration ranges is not clear. The total regenerated liquor flow was measured but the distribution between towers, which varies, is not known. SIGECO's analytical schedule for $SO_3^=$ in the regenerated liquor feed is used as a gauge for determining this distribution. The concentration should only change slowly because the regenerated liquor is a 3,500 gal/min stream from the 700,000 gallon thickener.

Other process data that were collected include boiler load, bisulfite concentrations, sulfate concentrations, and lime reactor pH. These data were were collected to cross check other data and to detect upset conditions that may affect SO_2 efficiency.

SIGECO Operating Procedures

Over the past 2 years, SIGECO has generally relied on a material balance calculation to determine compliance with the SO_2 emission standard and to guide the operation of the scrubbing system. The required percentage reduction in SO_2 emissions is calculated from coal analyses conducted on an as delivered basis. Next SIGECO calculates the potential sulfur dioxide emissions from the boiler load (MW), the plant heat rate and the coal sulfur content. The potential emissions are then multiplied by the required percent reduction to determine the amount of sulfur dioxide (moles/hr) that should be collected. The actual amount of sulfur dioxide that is collected is calculated from the change in sulfite ion mass flow between the liquor entering and leaving the scrubber. (If 1000 moles/hour $SO_3^=$ enter the absorber and 500 moles/hour leave the absorber then 500 moles/hour of SO_2 are being collected as indicated in Equation 4.) The amount of Na_2SO_3 entering the scrubber is based on analyses of the thickener overflow (three per day during the week and two per day on weekends) and the measured total regenerated liquor flow. The amount of sulfite leaving the scrubber can be calculated from the bleed flow (assumed to equal the regenerated liquor flow) and the pH of the bleed flow. The procedures require that the pH of both absorbers be averaged because each absorber cannot be treated individually since the individual liquid and gas flow rates are not known.

If the above procedure indicates that the unit is not in compliance, the operators then proceed to scrub more flue gas by adjusting the flow control dampers on one or both modules. At times, the dampers on the North and South absorbers are in different positions (i.e., the North might be 70 percent open while the South is 40 percent open). As a result, gas flows and SO_2 efficiencies are different between the two absorbers.

The above procedure, used to determine compliance, is extremely sensitive to the bleed pH since small changes in pH indicate relatively large changes in outlet $SO_3^{=}$ concentrations which in turn indicate significant changes in the amount of SO_2 collected. Because of this potential problem, SIGECO cleans and calibrates the pH probes three times per day during the week.

The scrubbing system responds automatically (as previously described) to changes in gas flow whether the changes are due to load changes or to operator adjustment of the dampers. Typically the boiler operates near full load (265 MW) during the day and near the minimum load (100 MW) at night. When the load increases the operator usually increases the opening of one or both flow control dampers.

If the SO_2 monitor is performing adequately, the operating mode is based on the monitor and pH becomes much less important as compliance is determined directly from the stack monitor. The flow control dampers are adjusted to achieve the SO_2 emission limit in a similar manner to the method previously discussed but the response in terms of SO_2 emissions or compliance are more dramatic and rapid than is currently the case. Basically damper position becomes more important and pH less important.

Soda ash is fed directly to the scrubber as indicated in Figure 9. Typically the valve is either set manually or automatically at 50, 75 or 100 percent of full flow. Usually the set point is only changed several times a week.

The other parts of the system operate automatically as previously discussed.

OPERATIONAL PROFILE

A. B. Brown No. 1 is the most expensive plant to operate in the SIGECO system. Therefore it is the last unit to be dispatched and the first to reduce load. The actual load profile during the test program was dependent on the weather and the availability of other units. In addition A. B. Brown No. 1 experienced pulverizer problems that forced load reductions. The average load during the test program was 50 percent of capacity although both higher and lower loads were also encountered.

During the test program, the average boiler load was 129 MWe. Figure 10 presents an hourly frequency distribution for boiler load. About 70 percent of the hourly average boiler loads were below 135 MWe.

Average excess air measured prior to the air preheater, was 36 percent. Oxygen concentrations at the same point averaged 5.45 percent. The range of observed oxygen concentrations is illustrated in the frequency distribution presented in Figure 11.

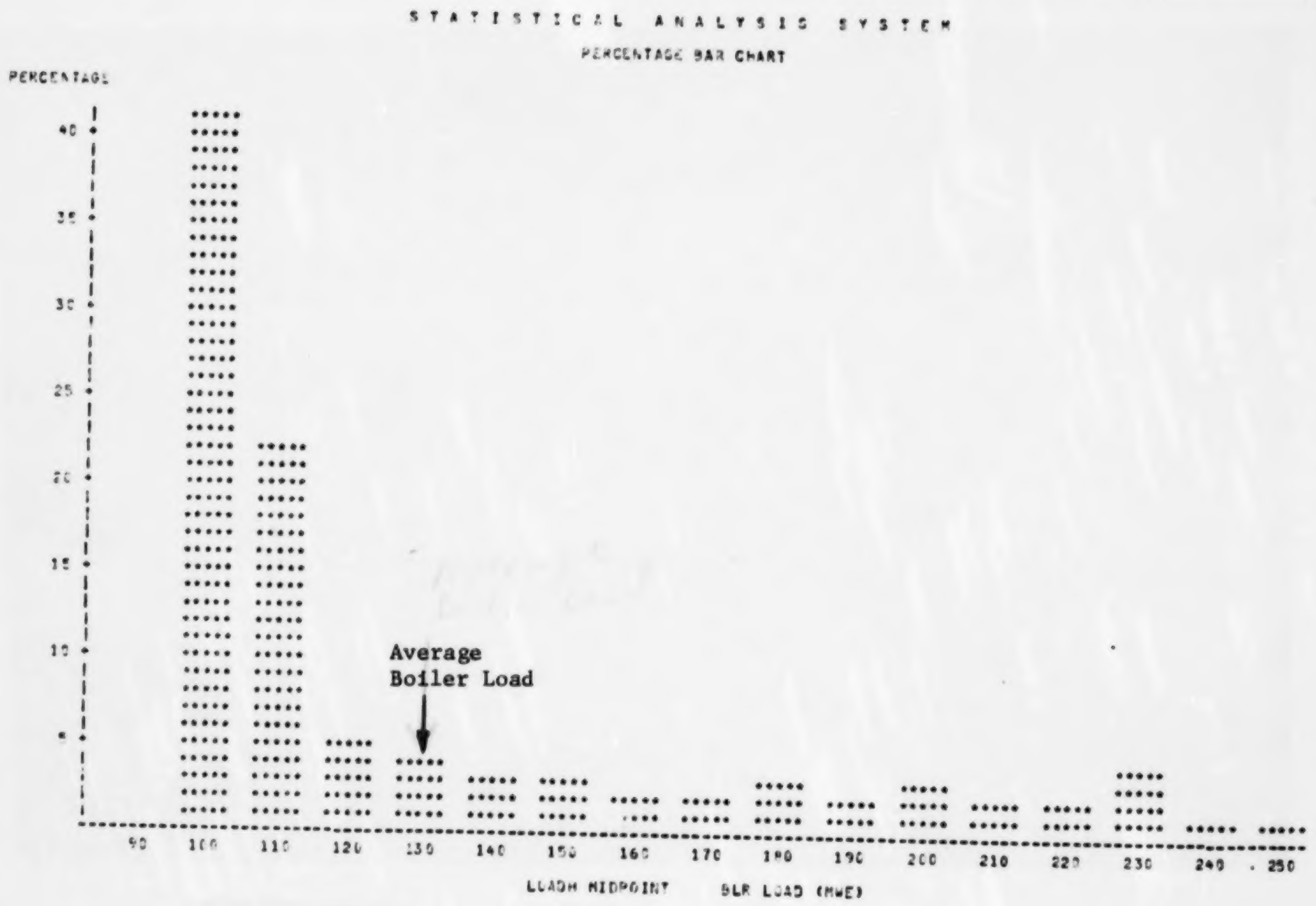


Figure 10. Hourly frequency distribution for boiler load.

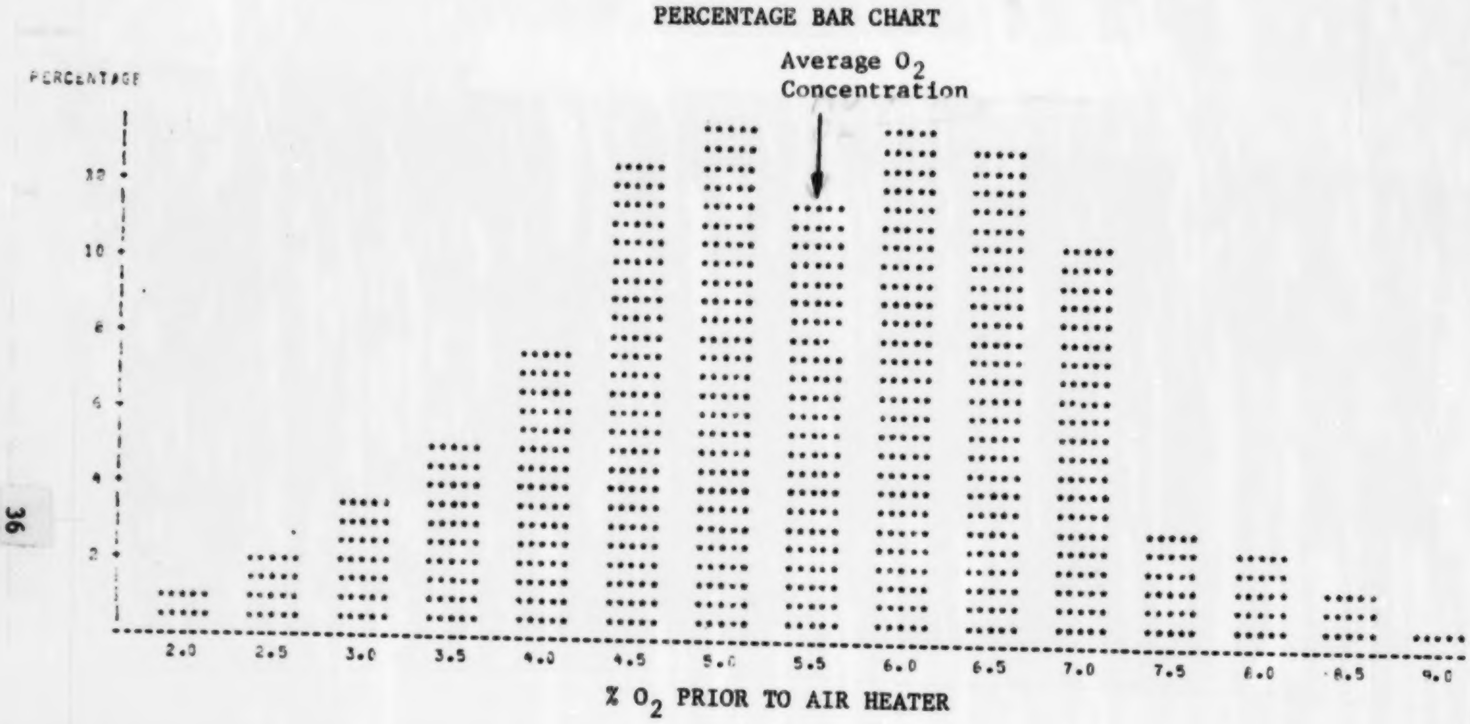


Figure 11. Hourly frequency distribution for oxygen concentration prior to the air preheater.

SECTION 4

TEST PROGRAM APPROACH

OVERVIEW

The test program was planned with five distinct segments or phases in mind as shown in Figure 12. Initially, a preliminary test approach was formulated by pursuing the four categories listed under preliminary test approach.

The background review task involved familiarizing test personnel with the specific aspects of the FMC scrubber system, both chemical as well as mechanical, and the operation principles and aspects of the B&W burner system. This review involved a survey of pertinent literature, review of several months of background data and discussions of the particular processes with the vendors.

Subsequently, an onsite inspection of the test facility was conducted. During this visit, historical data on the plant operation and available process data were reviewed to determine the critical plant operating parameters. Utilizing these data, GCA personnel assembled a prospective test approach.

The prospective test approach was discussed with FMC process engineers to determine if other aspects should be considered. Input and comments were incorporated into a preliminary test approach and presented to EPA for discussion.

Subsequently, the previously mentioned material was used as the basis for the ensuing technical approach. To fulfill the objectives of quantifying the performance of the SO_2 and NO_x control systems, GCA proceeded as shown in the remainder of Figure 12.

At the conclusion of the data collection phase, the process and emissions data were evaluated for correlation to control performance. The goal was to use the process data to explain variations in emission control performance.

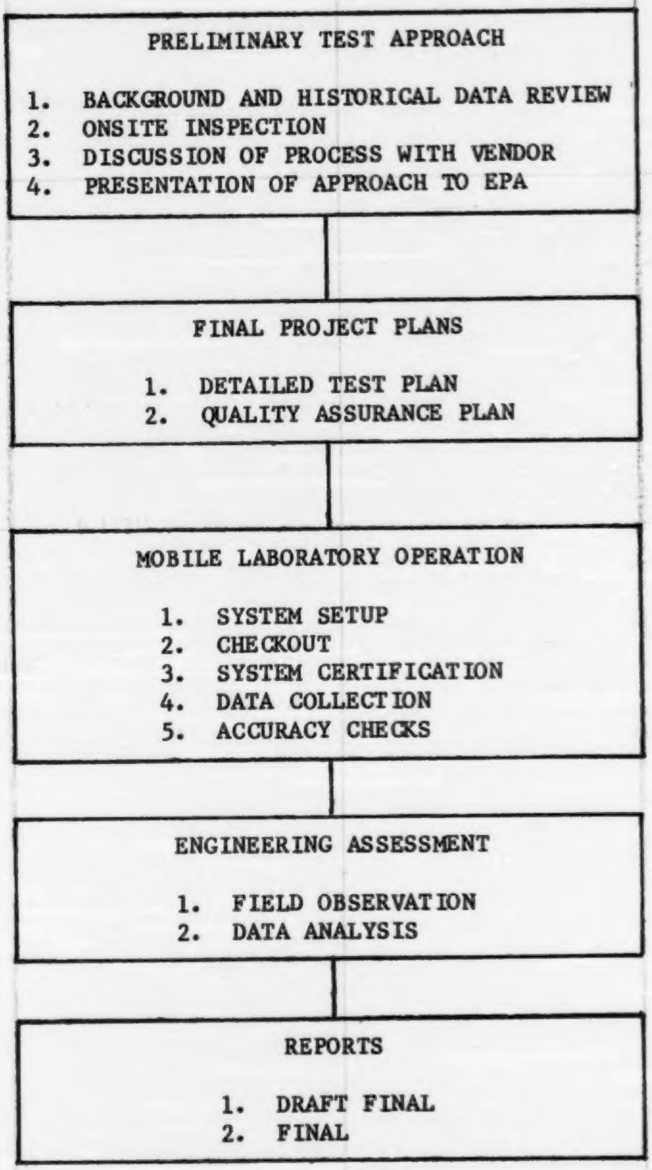

PRELIMINARY TEST APPROACH
1. BACKGROUND AND HISTORICAL DATA REVIEW
2. ONSITE INSPECTION
3. DISCUSSION OF PROCESS WITH VENDOR
4. PRESENTATION OF APPROACH TO EPA
FINAL PROJECT PLANS
1. DETAILED TEST PLAN
2. QUALITY ASSURANCE PLAN
MOBILE LABORATORY OPERATION
1. SYSTEM SETUP
2. CHECKOUT
3. SYSTEM CERTIFICATION
4. DATA COLLECTION
5. ACCURACY CHECKS
ENGINEERING ASSESSMENT
1. FIELD OBSERVATION
2. DATA ANALYSIS
REPORTS
1. DRAFT FINAL
2. FINAL

Figure 12. Program approach structure.

DATA REQUIREMENTS AND TESTING POINTS

NO_x Performance

The main emissions data requirements for evaluating the performance of the B&W wall-fired low NO_x boiler include carbon monoxide, oxides of nitrogen and diluent as close to the boiler effluent point (prior to the scrubber) and boiler excess air. The first three measurements mentioned were conducted at the inlet to each scrubber module as shown by Figure 6. Instrumentation was time shared on a 15 minute cycle as described in the measurement system subsection. Boiler excess air data were obtained from the plant owned and operated oxygen monitor which extracted its sample prior to the air preheater.

Carbon monoxide was envisioned as a gauge of combustion efficiency. This measurement was primarily used to identify "upset" conditions or atypical operating conditions when higher or lower than normal NO_x levels were noted.

NO_x emissions were calculated by averaging the measurements taken at the inlet locations. Process data available from the plant control room applicable to the NO_x performance aspect of the program included boiler load and secondary combustion airflow. As a result of the limited process data, the NO_x performance study was limited to the aforementioned parameters and the burner settings which remained unchanged throughout the duration of the program.

SO_2 Performance

The main emissions data required for quantifying modular scrubber performance are sulfur dioxide and oxygen at the inlets and outlets of each scrubber module. These measurements were conducted utilizing the instrumentation contained in the EPA mobile laboratory. Data were acquired on a semicontinuous basis by timesharing one set of instruments between the two inlet locations and a second set between the two outlet locations. Utilizing this approach, data were taken every 7-1/2 minutes and stored as a 15 minute average.

Carbon dioxide was monitored at the outlet location of each module for three (3) reasons. First, it supplied a redundant diluent measurement; second, in conjunction with the duct velocity, O_2 and gas stream temperatures supplied the data parameters for calculating volumetric flow rate, and third, the correlation between emission calculations involving CO_2 and O_2 based F factors could be ascertained. This monitor was also utilized in a time shared configuration.

The plant operated a stack monitoring system which measured SO_2/O_2 on a continuous basis. It was the original intent of GCA to acquire these data as a means for determining final stack emissions. However, the system was not operative during the test program due to hardware problems. These measurements were to provide data which could be used to calculate an equivalent bypass flowrate for each scrubber module. For quality control purposes, these data could also be compared to the primary program measurements conducted at the scrubber module locations.

To complement the primary emissions data, several scrubber parameters were acquired on a continuous basis. These parameters included tower and lime reactor pH's, module gas flow rates, total regenerated liquor flow rate, gross boiler load and opacity measurements at the inlet to each scrubber module. Other chemical data as previously described in Section 3 completed the data collected during this portion of the program.

MEASUREMENT SYSTEM

System Configuration

The primary emissions data were acquired utilizing the EPA mobile laboratory equipped with the sensors listed in Table 9. The mobile laboratory is configured to acquire emissions/process data from four locations producing data files containing 15-minute average data blocks. A flow schematic of the system is shown in Figure 13. Figures 14, 15, and 16 contain schematics of the valve switching box, the condensation/pumping system, and the sample distribution assemblies. These three subsystems are situated as shown in Figure 13.

The system cycled between the north and south tower locations by placing the respective valves contained in the valve switching box in the proper positions. Referring to Figure 13 for an overall view and Figure 14 for specific valve location, the north locations would be sampled when the south isolation, calibration and purge valves are in the closed position. The isolation valves are open on the north side and the calibration and purge valves are in the closed position. To sample the south tower, the north isolation valves open. All other valves are in the same closed positions as before. This valve sequence is maintained to extract a 7-1/2 minute sample from each tower, yielding a total cycling time of 15 minutes.

During the purge cycle, valves are positioned in order to free the system of particulate matter from the valve switching box to the probe filter. To effect a purge, the isolation valve is closed and the purge valve is opened. The calibration valve remains in its normally closed position.

Calibrations are conducted by activating the calibration valve to the open position at the location being calibrated. To calibrate the north location, all valves at both locations are in the closed position with the exception of the north calibration valves. When calibrating the south locations, all valves are closed except for the south calibration valves.

Sample conditioning is accomplished utilizing filtration for particulate removal and condensation for moisture removal. Large particulates are removed using a large surface area sintered in-stack filter. The smaller particulate matter is removed in the heated valve switching box using a low pressure drop

TABLE 9. MEASUREMENT SENSORS FOR A. B. BROWN CEMS

Parameter	Model/technique	Data recording	Comments
SO_2 (outlet)	DuPont 4000 (NDUV)	Fluke microprocessor and Auto Data 980	Cy
SO_2 (inlet)	Horiba PIR-2000 (NDIR)	Fluke microprocessor and Auto Data 980	Cy
NO_x (inlet)	TECO 10 AR (chemiluminescent)	Fluke microprocessor and Auto Data 980	Cy
O_2 (inlet)	MSA 802 (paramagnetic)	Fluke microprocessor and Auto Data 980	Cy
O_2 (outlet)	MSA 802 (paramagnetic)	Fluke microprocessor and Auto Data 980	Cy
CO_2 (outlet)	Horiba PIR-2000 (NDIR)	Fluke microprocessor and Auto Data 980	Cy
CO (inlet)	Horiba PIR-2000 (NDIR)	Fluke microprocessor and Auto Data 980	Cy
Volumetric gas flow rates	Annubar flow sensors (Dieterich standard)	Fluke microprocessor	C

CY = Instrument cycles between two locations--15-min cycle.

C = Continuous signal.

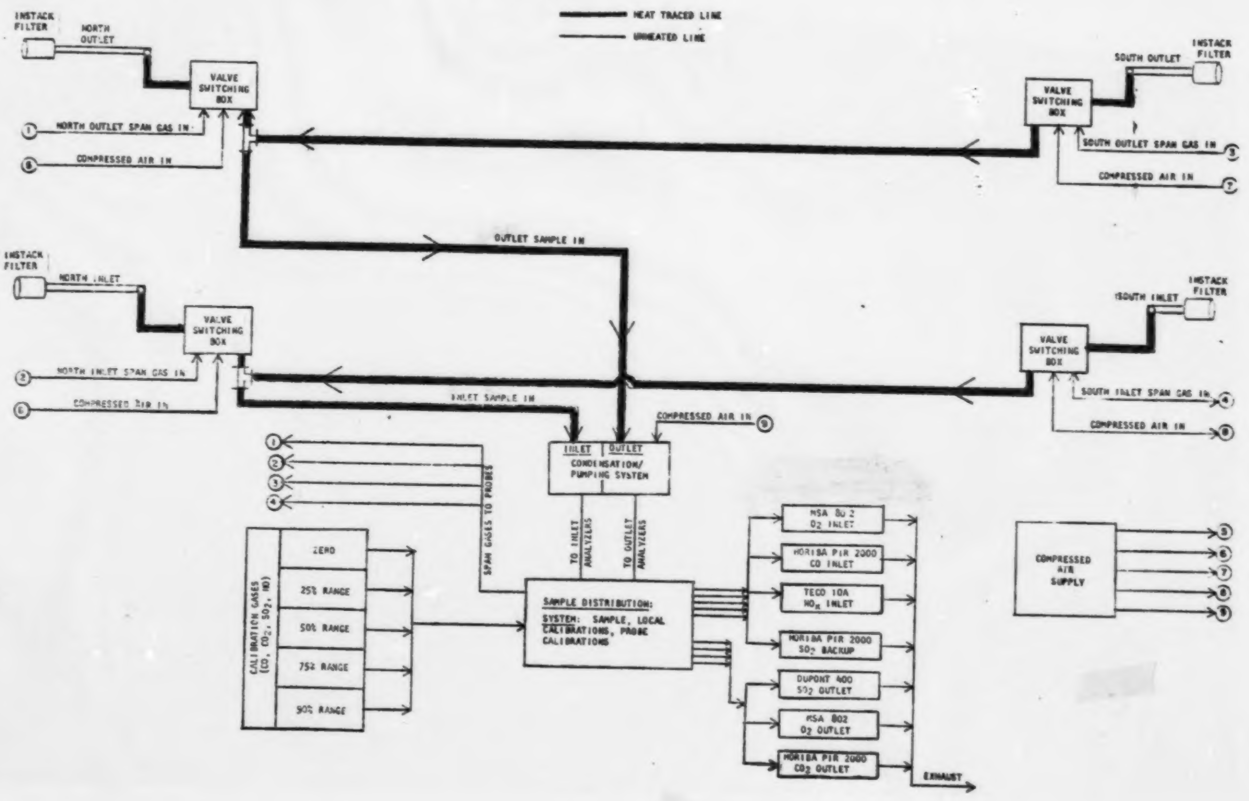

HEAT TRACED LINE
UNHEATED LINE
INSTACK FILTER
NORTH OUTLET
VALVE SWITCHING BOX
① NORTH OUTLET SPAN GAS IN
⑥ COMPRESSED AIR IN
INSTACK FILTER
SOUTH OUTLET
VALVE SWITCHING BOX
SOUTH OUTLET SPAN GAS IN ③
COMPRESSED AIR IN ⑦
OUTLET SAMPLE IN
INSTACK FILTER
NORTH INLET
VALVE SWITCHING BOX
② NORTH INLET SPAN GAS IN
⑥ COMPRESSED AIR IN
INSTACK FILTER
SOUTH INLET
VALVE SWITCHING BOX
SOUTH INLET SPAN GAS IN ④
COMPRESSED AIR IN ⑧
INLET SAMPLE IN
COMPRESSED AIR IN ⑨
INLET
OUTLET
CONDENSATION/ PUMPING SYSTEM
①
②
③
④
SPAN GASES TO PROBES
TO INLET ANALYZERS
TO OUTLET ANALYZERS
CALIBRATION GASES (CO, CO2, SO2, NO)
ZERO
25% RANGE
50% RANGE
75% RANGE
90% RANGE
SAMPLE DISTRIBUTION:
SYSTEM: SAMPLE, LOCAL CALIBRATIONS, PROBE CALIBRATIONS
MSA 802 O2 INLET
HORIBA PIR 2000 CO INLET
TECO 10A NOx INLET
HORIBA PIR 2000 SO2 BACKUP
DUPONT 400 SO2 OUTLET
MSA 802 O2 OUTLET
HORIBA PIR 2000 CO2 OUTLET
EXHAUST
COMPRESSED AIR SUPPLY
⑤
⑥
⑦
⑧
⑨

Figure 13. Mobile laboratory flow schematic.

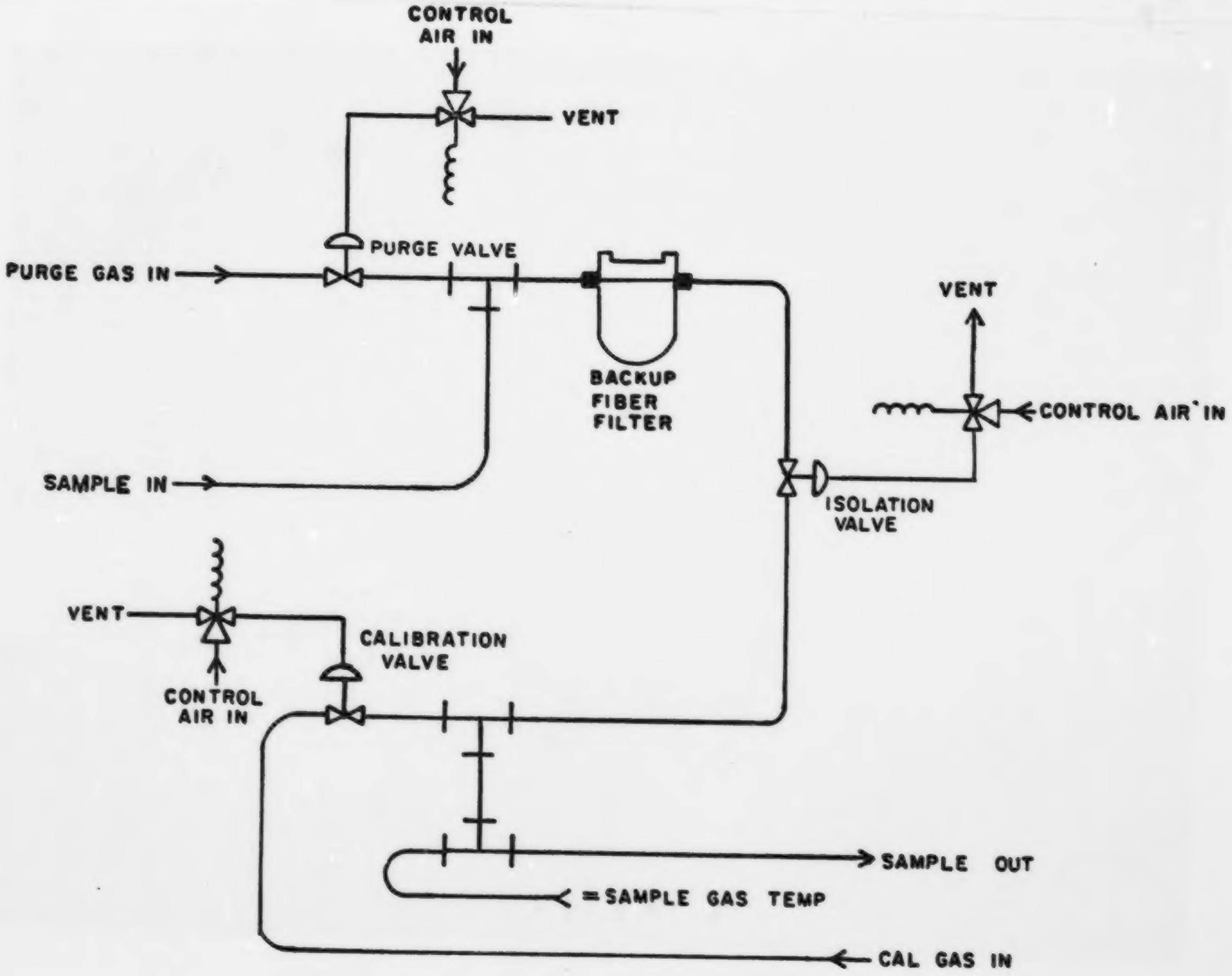

CONTROL AIR IN
VENT
PURGE VALVE
PURGE GAS IN
BACKUP FIBER FILTER
VENT
CONTROL AIR IN
SAMPLE IN
ISOLATION VALVE
VENT
CALIBRATION VALVE
CONTROL AIR IN
SAMPLE OUT
=SAMPLE GAS TEMP
CAL GAS IN

Figure 14. Valve box configuration.

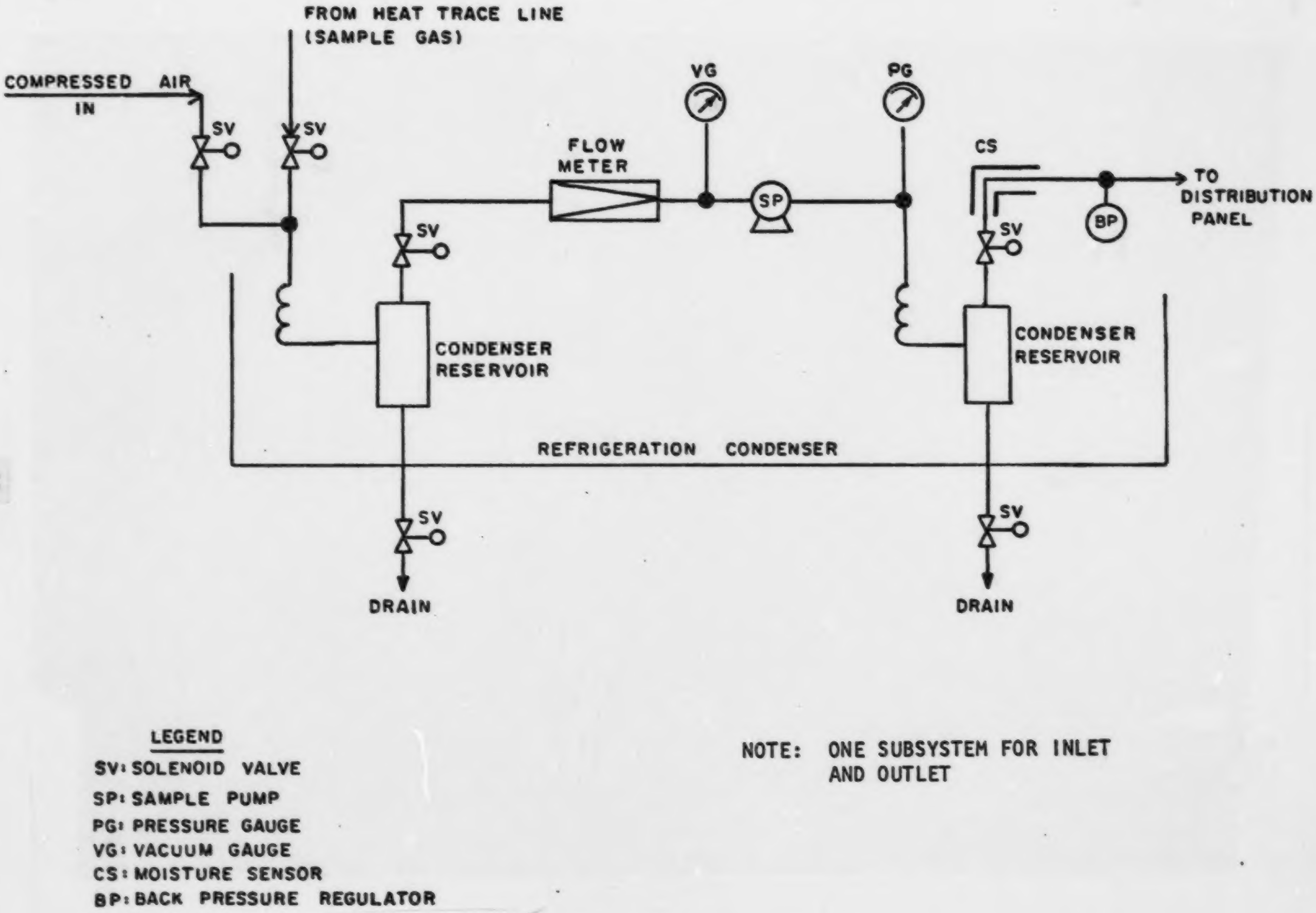

FROM HEAT TRACE LINE
(SAMPLE GAS)
COMPRESSED AIR
IN
SV
SV
VG
PG
FLOW
METER
SP
CS
SV
TO
DISTRIBUTION
PANEL
BP
CONDENSER
RESERVOIR
CONDENSER
RESERVOIR
REFRIGERATION CONDENSER
SV
SV
DRAIN
DRAIN
LEGEND
SV: SOLENOID VALVE
SP: SAMPLE PUMP
PG: PRESSURE GAUGE
VG: VACUUM GAUGE
CS: MOISTURE SENSOR
BP: BACK PRESSURE REGULATOR
NOTE: ONE SUBSYSTEM FOR INLET
AND OUTLET

Figure 15. Condensation/pumping system.

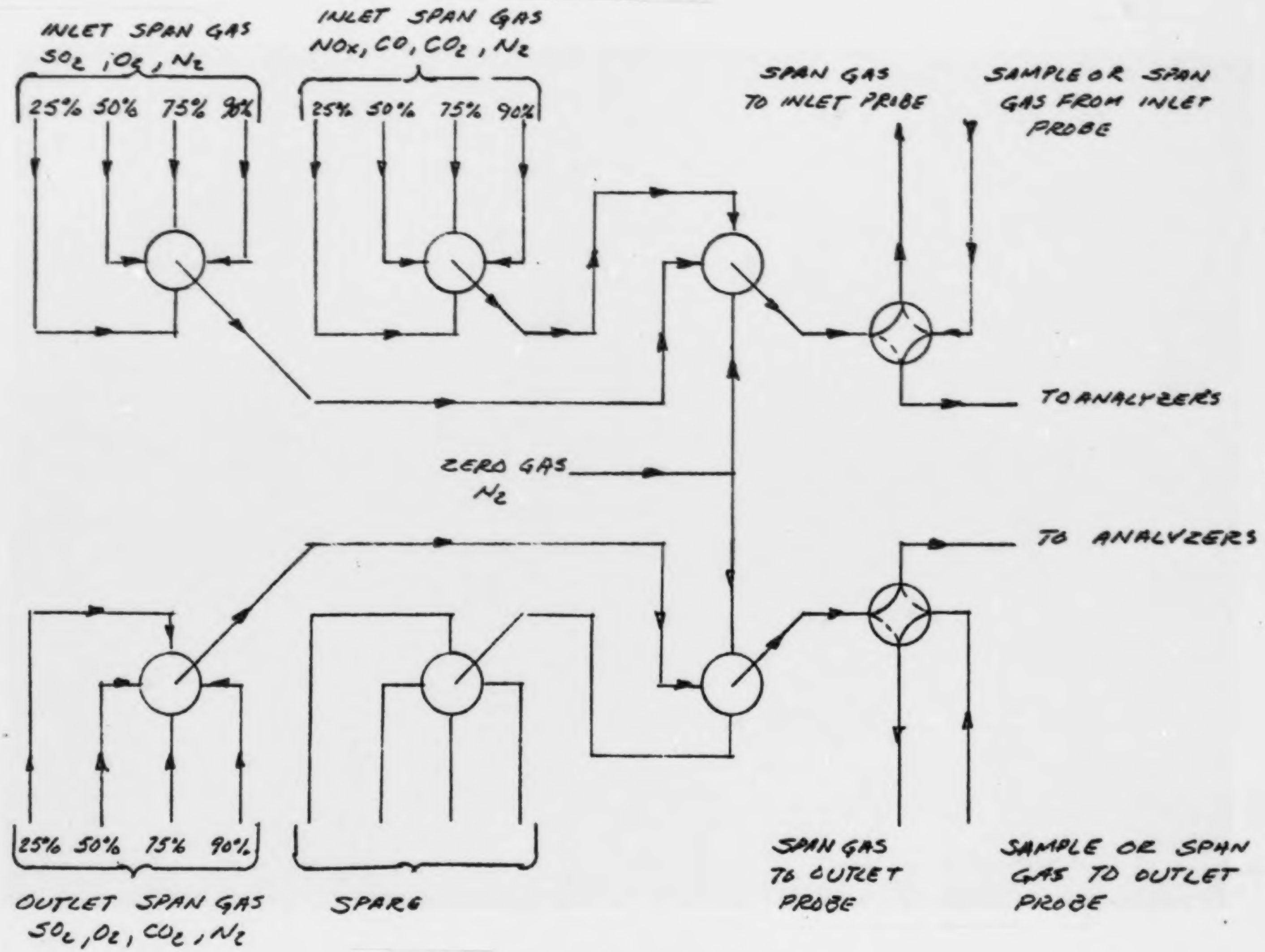

INLET SPAN GAS
SO_2, O_2, N_2
25% 50% 75% 90%
INLET SPAN GAS
NO_x, CO, CO_2, N_2
25% 50% 75% 90%
SPAN GAS TO INLET PROBE
SAMPLE OR SPAN GAS FROM INLET PROBE
TO ANALYZERS
ZERO GAS N_2
TO ANALYZERS
25% 50% 75% 90%
OUTLET SPAN GAS
SO_2, O_2, CO_2, N_2
SPARE
SPAN GAS TO OUTLET PROBE
SAMPLE OR SPAN GAS TO OUTLET PROBE

Figure 16. Sample distribution system.

glass fiber filter. The particulate free stream is transported through heat-traced teflon tubing to the condensation/pumping system. Moisture removal is accomplished by passing the sample through a dual pass condenser as shown in Figure 14. The first pass occurs under reduced pressure in which the pump draws the sample through the coil followed by a second pass under pressure in which final moisture removal is accomplished. At this point the sample gas is passed through the valve distribution system shown in Figure 15 which supplies a flow regulated sample stream to each instrument shown on Figure 13.

The mobile lab is equipped with a set of sensors for measuring inlet concentrations of CO, CO_2, NO_x, SO_2 and a set of sensors for measuring outlet concentrations of CO_2, O_2, and SO_2.

Concurrent with the emissions measurements, the process data shown in Table 10 were acquired on a continuous basis. The total data aquisition configuration that resulted is shown in Figure 17. This schematic depicts the interconnection of the sensors contained in the mobile laboratory with those sensors maintained and operated by SIGECO. All signals were acquired and processed using an onboard microcomputer. In addition to acquiring and scaling data and generating data reports, the computer system also provided a check on system status, initiated condensor blowdown and purges and provided an output signal to operate the cycling valves.

System Operation

Calibration--

During the field portion of the test program, GCA utilized a more stringent calibration routine than is normally conducted for compliance monitoring. Instruments were calibrated on a weekly basis by inputting span gases directly to the analyzers corresponding to zero and four upscale span concentrations. These concentrations corresponded to 25, 50, 75 and 90 percent of the effective measurement ranges. These calibration responses were recorded and subsequently used to calculate calibration equations for scaling the emissions data.

Calibration equations were calculated using regression curve fitting techniques. With the exception of the SO_2 and CO_2 monitors, linear regressions were used to convert monitoring voltages into engineering units. Responses for the SO_2 and CO_2 analyzers were scaled using a parabolic curve fitting technique.

The calibration equation was checked daily by inputting gases through the entire extraction system corresponding to zero, 50 percent and 90 percent of the full scale range. These responses were subsequently processed as a sample gas would be and output in engineering units utilizing the most current equation. This routine served the following purposes:

- Checked the system for leaks by observing the O_2 monitors
- Checked the calibration equation for zero and span drift

TABLE 10. PROCESS PARAMETERS

Parameter	Location	Range	Comments
Gross Generation	-	265 MWE	P
Total Regen. Flow	-	3000 gpm	P
Tower pH (North)	Bleed line	6.3-6.6	P, Q
Tower pH (South)	Bleed line	6.3-6.6	P, Q
Lime Reactor pH	Overflow outlet	8.3-8.7	P, Q
Opacity	North inlet	0-100%	P, LSI, RM 41
Opacity	South inlet	0-100%	P, LSI, RM 41
Secondary Airflow In	Boiler	30-100% capacity	P
Gas Flow Rate	North outlet	4 x 10^5 acfm	GCA
Gas Flow Rate	South outlet	4 x 10^5 acfm	GCA

P = Plant signal

GCA = GCA/EPA supplied sensor

Q = Daily QC checks

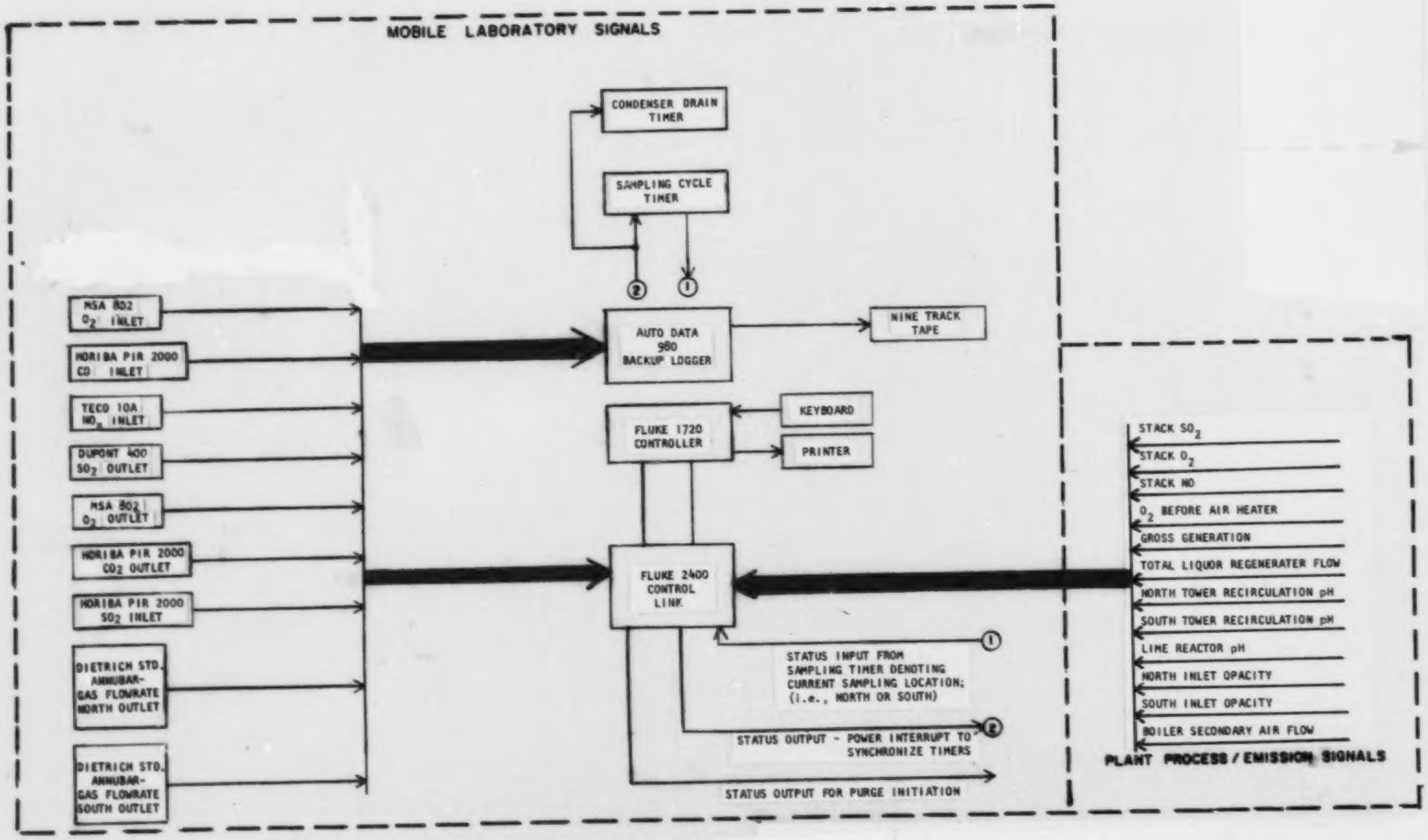

MOBILE LABORATORY SIGNALS
CONDENSER DRAIN TIMER
SAMPLING CYCLE TIMER
②
①
MSA 802 O_2 INLET
HORIBA PIR 2000 CO INLET
TECO 10A NO_x INLET
DUPONT 400 SO_2 OUTLET
MSA 802 O_2 OUTLET
HORIBA PIR 2000 CO_2 OUTLET
HORIBA PIR 2000 SO_2 INLET
DIETRICH STD. ANNUBAR-GAS FLOWRATE NORTH OUTLET
DIETRICH STD. ANNUBAR-GAS FLOWRATE SOUTH OUTLET
AUTO DATA 980 BACKUP LOGGER
NINE TRACK TAPE
FLUKE 1720 CONTROLLER
KEYBOARD
PRINTER
FLUKE 2400 CONTROL LINK
①
STATUS INPUT FROM SAMPLING TIMER DENOTING CURRENT SAMPLING LOCATION; (i.e., NORTH OR SOUTH)
②
STATUS OUTPUT - POWER INTERRUPT TO SYNCHRONIZE TIMERS
STATUS OUTPUT FOR PURGE INITIATION
STACK SO_2
STACK O_2
STACK NO
O_2 BEFORE AIR HEATER
GROSS GENERATION
TOTAL LIQUOR REGENERATER FLOW
NORTH TOWER RECIRCULATION pH
SOUTH TOWER RECIRCULATION pH
LIME REACTOR pH
NORTH INLET OPACITY
SOUTH INLET OPACITY
BOILER SECONDARY AIR FLOW
PLANT PROCESS / EMISSION SIGNALS

Figure 17. Data acquisition configuration.

- Provided the data inputs for calculating the proposed Appendix F Precision Estimates

- Allowed for the quick inspection and assessment of data quality.

Calibration gases utilized during the program were obtained from the vendor with an analytical certification of concentration. In addition, span gases (with the exception of the zero) were analyzed in triplicate using the applicable EPA reference method. Since carbon monoxide measurements were only made for process indication purposes, these span gases were not analyzed by reference method 10.

The instruments were operated in the ranges shown in Table 11. Instrument operating ranges were chosen such that the majority of the monitoring data were measured between 20 and 80 percent of the effective measurement ranges, where relative errors are less significant. Measurements conducted in the lower part of measurement ranges are subject to errors which can became large when compared to the measurement signals.

TABLE 11. INSTRUMENT OPERATING RANGES

Analyzer location	Range	Range	Normal process measurements range
Inlet SO_2	Horiba PIR-2000	0-5000 ppm	2000-3500 ppm
Inlet O_2	MSA Model 802	0-15%	6-10%
Inlet NO_x	Thermo Electron Model 10	0-750 ppm	150-225 ppm
Inlet CO	Horiba PIR-2000	0-500 ppm[a]	40-60 ppm
Outlet SO_2	DuPont Model 400	0-1000 ppm	100-700 ppm
Outlet O_2	MSA Model 802	0-15%	6-10%
Outlet CO_2	Horiba PIR-2000	0-21%	10-15%

[a] The minimum operating range for this instrument is 0-500 ppm.

Routine Data Acquisition--

Data were recorded on a continuous basis by a computer system which was connected to acquire the emission and process parameters listed in Tables 9 and 10. All parameters were acquired at a scan rate of 15 seconds and averaged on a 15-minute basis. The first seven emission entries in Table 10 were acquired by cycling between the two scrubber locations (North and South) as follows for each 15-minute period:

- Pump the sample from the North side for 5.0 minutes.
- Acquire data for next 2.5 minutes and store this as the 15-minute data value for the North side.
- Switch to South side and pump sample for 5.0 minutes.
- Acquire data for the next 2.5 minutes and store this value as the South module value.
- Repeat this sequence continuously to acquire quarter-hour data.

The remaining parameters listed in Table 9 and 10 were continuously acquired, averaged and stored as stated previously. Entries stored on disk were the raw signal responses and the reduced hourly averages.

A schematic of the total data generation/acquisition system was previously shown in Figure 17. Also shown on Figure 17 is a backup data logger. The system was equipped with an Autodate 980 logger which was connected in parallel to the emissions monitors (first seven entries in Table 9). This backup enabled GCA to ensure a high data capture rate during the program for the primary emissions parameters.

Data Reduction--

The monitoring data, calibration and calibration check data were stored on a floppy disk by the onboard computer system. These parameters were catalogued according to Julian date and time in the raw voltage (current) form. Data were acquired on a 15-minute basis, stored on disk and also printed out at the time of storage to provide a hard copy of the data.

The data were reduced onsite and a performance report generated for each of the scrubber modules and one for the low NO_x boiler. These reports were used by the mobile laboratory operators to verify proper system operation and as a check on the processes being evaluated.

Data reports generated onsite were not used in the final evaluation due to the fact that these report files were not screened or validated. Scaling factors used for these reports were not corrected for daily drift and therefore the data do not reflect the level of accuracy which is attainable.

Final data reduction was conducted using a time-shared computer. The raw calibration, calibration check and monitoring data were transferred from the Fluke Computer to the time shared computer using a modem link. These data included the raw calibration, calibration check, and monitoring responses. Periods of missing data were taken care of by hand inserting data acquired by the backup logger or data obtained from process operating logs. Periods of data loss were experienced because of frequent computer crashes which occurred. Completed data files were reprocessed resulting in the data tables contained in Volumes III, IV and V of this report.

TEST PROCEDURES

Continuous Measurements

Continuous measurements were conducted using instrumentation operating on the principles listed in Table 12. Outlet concentrations of SO_2 were measured using the DuPont Model 400 nondispersive ultraviolet monitor (NDUV). This unit measures the attenuation of the continuum UV source by SO_2 and isolates the optimum absorption band using an optical filter.

TABLE 12. CONTINUOUS DETECTION PRINCIPLES

Pollutant/ parameter	Make/model	Principle	Location(s)
SO_2	DuPont Model 400	NDUV	Outlet
NO_x	TECO 10AR	Chemiluminescence	Inlet
O_2	MSA 802	Paramagnetic	Inlet/Outlet
CO_2	Horiba PIR-2000	NDIR	Outlet
CO	Horiba PIR-2000	NDIR	Inlet
SO_2	Horiba PIR-2000	NDIR	Inlet
Gas flowrate	Dietrich Std Annubar	Bernoulli's Principle	Outlet

Oxygen concentrations at the inlets and outlets of each scrubber module were measured using the MSA Model 802 paramagnetic analyzer. The detection principle is based on the paramagnetic properties of O_2 at high temperatures in a magnetic field.

Total oxides of nitrogen were monitored using the TECO Model 10AR chemiluminescence NO_x analyzer. The detection principle is based on the gas phase reaction that occurs between nitric oxide (NO) and ozone (O_3) as shown below:

$$NO + O_3 \rightleftharpoons NO_2^* \qquad (9)$$

$$NO_2^* \rightleftharpoons NO_2 + h \qquad (10)$$

Excess O_3 instantaneously reacts with the NO molecules in the sample gas to form nitrogen dioxide (NO_2) molecules at an elevated energy state (NO_2*). When excited NO_2 molecules return to the ground state, a characteristic wavelength of light is emitted (chemiluminescence) which is proportional to the original concentration of NO. This intensity is sensed by a photomultiplier tube and processed electronically to provide a signal proportional to the NO concentration.

To provide a signal proportional to the total NO_x concentration, the Model 10AR is equipped with a converter that quantitatively reduces NO_2 to NO. The NO concentration is then determined using the chemiluminescence technique.

Carbon Monoxide, SO_2 and CO_2 concentrations were measured using the Horiba Model PIR-2000 nondispersive infrared (NDIR) analyzers. The detection principle of these analyzers is based on the absorption of infrared radiation by the pollutant laden sample gas. Horiba utilizes a narrow optical band pass filter to minimize the cross sensitivity of this technique.

Module gas flowrate was meausured continuously at each scrubber outlet location using an annubar velocity measuring device coupled with an electronic pressure tranducer. The flow measurement system is an averaging type pitot tube which operates according to Bernoulli's principle of fluid flow across a fixed body. Average velocity heads (inches of water) are sensed by the electronic transducer and processed according to the following equation:

$$Q_a = 264611 \sqrt{\Delta p} \tag{11}$$

where 246611 is a calibration constant supplied by the manufacturer accounting for the gas density, moisture fraction, and the length of the annubar.

Stratification

Prior to performance testing and the initiation of monitoring, stratification tests were conducted at each monitoring location. The purpose of this procedure was to verify a homogeneous gas stream and, if one did not exist, to determine a point of average concentration for placing the monitor probes. This test consisted of measuring the pollutant and diluent concentrations at 18 traverse points for 3 minutes each. Between each pair of ports, the monitoring system was switched to a reference traverse point for 3 minutes. The data obtained from the reference test point was utilized to correct for temporal process variations in the test data that resulted since the test required several hours to conduct. temporal variations in the flue stream are those changes in concentration which are caused by the variability of the process. Since measurements made over a period of time may be effected by process variability, temporal corrections are used to correct the data back to a common reference point. Data collected at each traverse point, after being corrected for temporal variations, were utilized to define the spatial variation of the flue stream. The stratification procedure was conducted initially at all locations and twice thereafter at the outlet locations only. This testing occurred during the abbreviated relative accuracy testing, discussed in subsequent paragraphs.

The stratification data were corrected for temporal variations according to the following equation:

$$E_{SO_2} \text{ corrected}_i = \left[\frac{E_{SO_2 \text{ ave ref}}}{E_{Ref(n)} + E_{Ref(n+1)}} \right] \quad (12)$$

where E_{SO_2} is the emission rate for SO_2 at traverse point i, ng/J.

E_{SO_2} Ave Ref. is the average SO_2 emission rate for all reference points.

$E_{Ref(n)}$ and $E_{Ref(n+1)}$ are the SO_2 emission rates of the individual reference points.

Temporally corrected data is then averaged, the standard deviation calculated and relative difference determined between the average reference value and each average temporally corrected traverse value.

System Certification

Following the stratification testing, both systems were certified according to the proposed Appendix B Performance Specifications Tests. (October 10, 1979). These tests specify a criteria for assessing the system performance. Table 13 lists the performance criteria as specified in proposed Performance Specifications Tests 2 (SO_2/NO_x), 3 (O_2/CO_2), and 4 (CO). The complete testing sequence was performed after an initial conditioning period on the North Tower only. Since the same instrumentation system was used to cycle between the north and south locations, an abbreviated relative accuracy test was considered satisfactory for the south location. An abbreviated relative accuracy test consisted of six replicates.

Relative accuracy tests were not conducted for the carbon monoxide analyzer because it was only used to note process variations in combustion efficiencies. Also this pollutant is not regulated for utility combustion sources.

Abbreviated Relative Accuracy

As an ongoing check of system accuracy, an abbreviated relative accuracy test was conducted at all monitoring locations on a monthly basis. In all, a test was conducted at the midpoint and at the conclusion of the field portion of the program.

Volumetric Gas Flow Rate Verification

As a calibration check for the continuous annubar measurement device, GCA conducted two calibration checks. Initially the transducer calibration equation for the pressure transducer was checked against an inclined manometer for pressure drops between 0 to 4 inches W.G. Subsequently, the entire assembly (transducer and annubar) was checked by conducting a concurrent measurement using EPA Reference Method 2.

TABLE 13. PERFORMANCE SPECIFICATION TEST CRITERIA

Test	CO[a]	SO_2/NO_x	CO_2/O_2
Conditioning period	≥168-hr	≥168-hr	≥168-hr
24-hr zero drift	≤2% span	≤2% span	≤0.5% O_2 (CO_2)
24-hr cal. drift	≤2.5% span	≤2.5% span	≤0.5% O_2 (CO_2)
2-hr zero drift (optional)	≤1% span	≤2% span	≤0.4% O_2 (CO_2)
2-hr cal. drift (optional)	≤2% span	≤2% span	≤0.4% O_2 (CO_2)
Mid-level cal. error	≤5%	≤5%	≤5%
High-level cal. error	≤5%	≤5%	≤5%
Response time	≤10 min	≤15 min	≤15 min
Relative accuracy	≤10% of the mean reference value	≤20% of the mean in terms of emission rate	

[a] Certification of the CO monitor is not required for coal-fired boilers.

Process Calibration Checks

Plant process signals were verified where possible. The opacity monitors were zeroed and spanned daily by the control room operators utilizing interference filters. Since these instruments were only useful to the program for determining precipitator upset conditions, further checks were not conducted.

Process pH meters were verified periodically by plant personnel and these data were utilized for correcting calibration drifts. These monitors were typically calibrated every 8 hours. Additional checks were made by the plant personnel if the responses of the instruments were thought to be questionable.

CHEMICAL ANALYSES

On a daily basis, SIGECO conducts routine measurements to determine pH, specific gravity, and bisulfite/sulfite. Periodically the filter cake is analyzed for moisture content and percent soluble and insoluble material.

Tower and lime reactor pH measurements were conducted by the SIGECO laboratory at least once per shift. The primary purpose of these measurements is to verify the accuracy of the continuous pH monitors which are the bases for operating the scrubber system. Measurements are conducted at the actual measurement location using a portable pH monitor and again in the laboratory using a more precise method. The local measurement is used to readjust the monitor and the laboratory measurement is used to verify the local measurement and for estimating $SO_3^=/H_{SO_3}$ ratios.

Daily measurements of the recirculation scrubbants and the regenerated return for $SO_3^=$ and HSO_3^- are conducted using a titrimetric procedure recommended by FMC. The bisulfite concentration is determined indirectly by initially conducting an acid base titration to determine the total $SO_3^=/HSO_3^=/SO_4^=$ concentration. Subsequently, the $SO_3^=/SO_4^=$ are precipitated with barium chloride and the solution retitrated. The bisulfite concentration is determined by taking the difference bewteen the two titrations.

Sulfite is determined by titrating an aliquot of the sample to a bromocresol green end point with standard hydrochloric acid titrant.

Periodically, filter cake samples were sent out to a local laboratory to determine free moisture, percent soluble salts, percent insoluble solids, bulk density and available alkali content.

QUALITY ASSURANCE OVERVIEW

The quality assurance approach utilized at A. B. Brown involved techniques designed to independently evaluate the representativeness of the sampling locations as well as the precision and accuracy of the monitoring system responses. Individual quality assurance checks and techniques utilized during the program are listed in Table 14.

This program basically involved the maintenance of a structured calibration program, the use of reference method testing for comparison purposes, estimation of data precision and the documentation of the flue gas stratification at each sampling location.

With the exception of the daily zero and span checks and the performance specification tests, the remainder of the quality assurance activities were included to fulfill the precision and accuracy requirements for the program.

The calibration protocol was adopted in order to accurately determine the response characteristics of each analyzer. Since NDIR analyzers were utilized (which often times are non-linear) the use of a multipoint calibration approach enables an operator to determine the true response curve.

An extension of this calibration sequence was the use of a three point calibration check which was conducted on a daily basis. This routine involved the analyses of control standards corresponding to 0, 50 and 90 percent of the instrument operating range. When "out of control" conditions were signalled by these control standards, a new calibration curve was constructed.

TABLE 14. QUALITY ASSURANCE CATEGORIES

Traceable Calibration Standards
Weekly Multipoint Calibrations
Daily zero and upscale Calibration Checks
Monthly Stratification Tests
Performance Specifications Tests
Ongoing Precision Estimates
Monthly Abbreviated Relative Accuracy Tests
Independent Quantitative Performance Audits

Data obtained from the three point control check was also utilized to estimate the precision and accuracy of the data generated by each analyzer. These estimates were determined using the following equations contained in the Draft Quality Assurance Guidelines which will be promulgated as Appendix F of 40 CFR 60.

Percentage Difference (d_i)

$$d_i = \frac{Y_i - X_i}{X_i} (100) \qquad (13)$$

where: Y_i = Monitor indicated concentration from the i-th precision check.

X_i = The precision check reference concentration used for the i-th precision check.

Monthly average percent difference ($\overline{d}_j$)

$$\overline{d}_j = \frac{1}{n} \sum_{i=1}^{n} d_1 \qquad (14)$$

where: n = number of valid precision checks made during the calender month j.

Standard deviation of the percent difference (S_j)

$$S_j = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} d_i^2 - \frac{1}{n} \left(\sum_{i=1}^{n} d_i \right)^2} \qquad (15)$$

Upper and lower 95 percent probability limits (UPL and LPL)

$$\text{UPL} = \bar{d}_j + 1.96\ S_j \qquad (16)$$

$$\text{LPL} = \bar{d}_j - 1.96\ S_j \qquad (17)$$

Confidence intervals for the daily zero check were calculated using the same equations except that X_i in equation (13) is assigned the value of the instrument full scale operating range.

The last three entries in Table 14 are independent checks designed to assess system performance and the representativeness of the sampling location. With the exception of the performance audit, these checks were conducted on a monthly basis by GCA.

The performance audit was conducted by an EPA contractor during the setup phase of the program. This technique involved the utilization of field useable standards by the auditors to assess the accuracy and quality of the monitoring data. Parameters checked included the analyzer calibrations, the manual sampling volume meter accuracies, and the accuracy of the reference method analytical procedures. Results of these audits were forwarded in report form to the EPA project officers.

SECTION 5

EMISSION CONTROL PERFORMANCE AND PROCESS PARAMETER CORRELATIONS

OXIDES OF NITROGEN

Emission Control Performance

At A. B. Brown, NO_x emissions are controlled by boiler design and operation. Babcock and Wilcox dual register burners are probably the primary reason for the observed low emission rates for NO_x. Daily averages for NO_x emissions and other related data are presented in Table 15. The highest observed NO_x daily average emission rate was 219 ng/J (0.51 lb/10^6 Btu) which is equivalent to 70 percent of the 1971 NSPS of 301 ng/J (0.7 lb/10^6 Btu). The mean emission rate was 163 ng/J (0.377 lb/10^6 Btu) or 54 percent of the 1971 NSPS.

Results for the observed 30-day rolling averages are presented in Table 16. The observed 30-day rolling averages ranged from 160 ng/J (0.37 lb/10^6 Btu) to 167 ng/J (0.39 lb/10^6 Btu).

Hourly data including some descriptive statistics are summarized in Table 17. The mean emission rate for NO_x, based on 1365 hourly data points, was 163 ng/J (0.38 lb/10^6 Btu) with a standard deviation of 15.8 ng/J and a standard error of the mean equal to 0.43. A 95 percent confidence interval for any single hourly reading would be 162 ± 31.6 ng/J (equivalent to ± 1.96 standard deviations). The true long term hourly mean for this plant can be estimated to be 163 ± 0.84 ng/J based on the standard error of the mean.

The range of observed hourly NO_x emission rates are described in the frequency distribution presented in Figure 18. All hourly readings were less than 210 ng/J or 70 percent of the 1971 NSPS. In addition, 89 percent of the hourly results were below 180 ng/J or 60 percent of the 1971 NSPS.

The operating conditions under which these NO_x emission rates were observed are summarized in previously mentioned Table 17. Average boiler load was 129 MWe, about 50 percent of capacity. Excess air near the boiler exit (prior to the air preheater) averaged 36.4 percent (5.45 percent O_2). Carbon monoxide concentrations corrected to 0 percent excess air averaged 63 ppm. The influence of operating parameters on the observed hourly emission rates is discussed in the next section.

TABLE 15. SUMMARY OF DAILY AVERAGED NO_x DATA

NOX PERFORMANCE SUMMARY

DAILY DATA CEM DATA						NORTH				SOUTH				TOTAL EMISSIONS		
DAY	TIME	BLR LOAD (MWE)	SEC AIR FLOW KPPHR	%O2 PRIOR AIR HTR	% EXCESS AIR	NOX PPM	%O2	CO PPM	E NOX NG/J	NOX PPM	%O2	CO PPM	E NOX NG/J	E NOX AVE.	STOICH CO PPM	% NOX STD.
212	0000	99	1246	5.31	34.1	183	8.01	34	149	***	*****	***	***	149	***	***
213	0000	141	1578	5.53	36.2	200	7.29	49	155	***	*****	***	***	155	***	***
214	0000	137	1610	6.08	41.2	203	8.26	34	170	***	*****	***	***	170	***	***
215	0000	118	1476	6.36	43.9	183	8.81	32	159	***	*****	***	***	159	***	***
216	0000	132	1504	5.89	39.4	208	8.24	39	173	***	*****	***	***	173	***	***
217	0000	113	1416	6.25	42.7	197	8.50	36	166	***	*****	***	***	166	***	***
218	0000	142	1604	6.44	44.7	216	7.67	40	171	221	7.25	67	170	170	75	56
219	0000	115	1410	6.75	47.6	205	7.77	33	164	207	7.32	39	161	162	54	53
220	0000	105	1297	7.06	51.0	202	8.38	34	169	202	7.92	34	163	166	52	54
221	0000	104	1331	7.33	54.1	201	8.50	34	170	202	8.19	34	167	168	53	55
222	0000	160	1764	6.76	48.0	215	7.44	37	169	219	7.05	43	166	167	57	55
223	0000	121	1463	6.87	49.1	204	8.92	34	179	212	8.52	37	180	179	58	59
224	0000	134	1582	6.59	46.2	202	8.31	48	169	206	7.53	103	164	166	105	54
225	0000	161	1585	6.49	45.2	217	7.48	39	171	216	6.59	54	161	166	65	54
226	0000	178	1816	6.31	43.5	207	7.53	37	161	217	6.87	42	162	161	57	53
227	0000	101	1293	6.40	44.2	175	9.43	39	159	196	8.34	42	164	161	66	52
228	0000	102	1352	6.25	42.7	189	9.08	38	167	199	8.74	38	170	169	61	55
229	0000	112	1407	6.19	42.2	199	8.67	37	171	204	6.28	43	171	171	62	56
230	0000	173	1806	5.68	37.5	227	7.43	37	177	235	6.47	49	172	174	59	57
231	0000	173	1763	5.56	36.4	226	7.43	35	177	232	6.58	72	171	174	73	57
232	0000	178	2030	4.60	28.3	219	7.29	34	170	222	6.63	108	165	167	95	55
233	0000	166	1946	4.50	27.8	223	7.60	31	177	227	6.38	126	165	170	106	56
234	0000	131	1635	4.99	31.5	208	9.00	32	164	208	8.44	62	177	180	72	59
235	0000	143	1671	5.55	36.2	209	8.37	30	176	208	7.58	62	165	170	68	56
236	0000	209	1947	5.37	34.7	217	6.97	30	164	217	5.95	61	152	158	62	51
237	0000	177	1900	5.28	33.9	201	7.64	32	160	201	6.62	54	150	155	60	50
238	0000	129	1557	5.44	35.2	198	6.51	30	168	196	7.80	41	157	162	54	53
239	0000	106	1350	4.37	26.5	192	9.39	30	175	189	8.56	37	161	168	54	55
240	0000	109	1402	5.32	35.9	193	6.67	31	168	183	8.91	38	161	164	55	54
241	0000	141	1655	5.18	34.1	202	7.87	42	163	203	7.84	60	164	163	74	53
242	0000	142	1764	6.69	54.9	191	6.10	48	159	169	7.55	45	147	154	67	50
243	0000	139	1704	4.14	24.8	161	8.26	69	152	184	8.02	68	151	152	97	49
244	0000	111	1467	4.36	26.4	185	9.29	34	168	182	8.45	35	154	161	57	52
245	0000	104	1365	4.22	25.4	173	9.61	32	161	180	8.78	34	156	159	54	52
246	0000	102	1402	4.28	26.0	***	*****	***	***	***	*****	***	***	***	***	***
247	0000	102	1379	3.93	23.5	***	*****	***	***	***	*****	***	***	***	***	***
248	0000	112	1446	4.12	24.8	199	6.96	33	175	201	7.84	36	161	168	53	55
249	0000	99	1331	4.41	27.0	182	9.64	32	169	184	8.65	36	157	163	55	53
250	0000	123	1528	3.49	20.2	164	8.64	32	160	185	7.81	35	146	154	51	50
251	0000	190	1670	2.65	14.6	146	7.89	86	149	192	6.73	80	142	148	67	46

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TABLE 15 (continued)

NOX PERFORMANCE SUMMARY

DAILY DATA CEM DATA						NORTH				SOUTH				TOTAL EMISSIONS		
DAY	TIME	BLR LOAD (MWE)	SEC AIR FLOW KPPHR	%O2 PRIOR AIR HTR	% EXCESS AIR	NOX PPM	%O2	CO PPM	E NOX NG/J	NOX PPM	%O2	CO PPM	E NOX NG/J	E NOX AVE.	CO PPM	STOICH % NOX STD.
252	0000	153	1700	2.85	15.8	177	6.62	36	137	176	6.15	83	134	135	67	44
253	0000	167	1753	3.61	21.3	185	7.76	34	149	193	6.68	97	143	146	88	47
254	0000	191	2147	4.25	27.1	207	6.94	36	157	205	5.99	140	146	151	113	49
255	0000	117	1387	4.91	30.9	182	8.78	34	159	182	8.08	35	149	154	54	50
256	0000	109	1388	4.74	29.4	180	8.81	35	156	181	8.32	32	150	153	54	50
257	0000	157	1689	3.93	23.4	194	7.36	35	150	190	6.55	126	139	144	108	47
258	0000	114	1445	5.04	32.0	195	9.02	27	173	187	8.55	28	159	166	45	54
259	0000	122	****	****	****	190	9.71	26	178	188	9.25	28	169	173	46	56
260	0000	100	1391	3.54	20.5	185	9.87	28	176	187	9.30	29	169	172	50	56
261	0000	97	1391	4.51	28.6	183	10.24	27	180	182	9.72	30	171	175	51	57
262	0000	***	****	****	****	***	*****	***	***	***	*****	***	***	***	***	***
263	0000	***	****	****	****	***	*****	***	***	***	*****	***	***	***	***	***
264	0000	98	1397	5.02	31.8	237	9.64	28	221	248	8.94	30	217	219	48	72
265	0000	106	****	****	****	223	9.83	26	211	229	9.37	28	206	209	46	68
266	0000	106	****	****	****	223	9.34	26	203	215	9.12	29	195	198	47	65
267	0000	119	1555	5.10	32.5	215	9.22	28	193	213	9.07	30	169	191	46	62
268	0000	109	1428	4.81	30.0	219	8.92	29	191	217	8.90	30	190	190	49	62
269	0000	107	****	****	****	216	9.10	28	191	212	9.09	29	188	189	48	62
270	0000	106	1307	4.69	29.1	222	9.09	24	197	222	9.02	26	195	196	41	64
271	0000	108	1344	7.04	54.2	232	8.93	21	203	230	8.65	24	197	200	37	66
272	0000	120	1527	7.98	61.9	232	9.15	21	207	227	9.04	39	201	204	46	67
273	0000	143	1589	7.38	54.8	236	7.90	24	191	229	8.04	59	188	169	63	62
274	0000	126	1487	6.94	49.8	235	8.27	23	199	218	7.87	69	179	189	66	62
275	0000	105	1416	6.14	41.8	208	9.09	22	185	209	8.95	21	183	164	35	60
276	0000	105	1428	6.78	48.2	206	9.39	20	188	211	9.04	19	187	187	33	61
277	0000	101	1375	6.67	47.0	198	9.21	21	177	201	8.66	21	172	175	34	57
278	0000	156	****	****	****	213	8.02	61	173	214	7.77	73	171	172	95	56
279	0000	134	****	****	****	218	8.86	22	190	218	8.88	21	191	190	35	62
280	0000	151	****	****	****	224	7.90	46	183	224	7.93	42	183	182	62	60
281	0000	191	1883	8.22	65.0	224	6.53	38	165	231	6.37	62	167	166	68	54

TABLE 16. NO_x EMISSIONS, 30-DAY ROLLING AVERAGES

Day	BLR Load (MWE)	Daily average NO_x (ng/J)	30-day rolling average (ng/J)	Day	BLR Load (MWE)	Daily average NO_x (ng/J)	30-day rolling average (ng/J)
212	99	149	0	247	102	[a]	162
213	141	155	0	248	112	168	162
214	137	170	0	249	99	163	163
215	118	159	0	250	123	164	162
216	132	173	0	251	158	143	162
217	113	166	0	252	153	135	162
218	142	170	0	253	167	146	162
219	115	162	0	254	191	151	161
220	105	166	0	255	117	154	161
221	104	168	0	256	109	153	161
222	160	167	0	257	157	144	160
223	121	179	0	258	114	166	161
224	134	166	0	259	122	173	160
225	161	166	0	260	100	172	161
226	178	161	0	261	97	175	160
227	101	161	0	262[b]	--	--	--
228	102	169	0	263[b]	--	--	--
229	112	171	0	264	98	219	160
230	173	174	0	265	106	209	161
231	173	174	0	266	106	198	162
232	178	167	0	267	119	191	163
233	166	170	0	268	109	190	164
234	131	180	0	269	107	189	164
235	143	170	0	270	106	196	164
236	209	158	0	271	108	200	164
237	177	155	0	272	120	204	165
238	129	162	0	273	143	189	166
239	106	168	0	274	126	139	167
240	109	164	0	275	105	184	167
241	141	163	160	276	105	187	167
242	142	154	160	277	101	175	167
243	139	152	160	278	156	172	166
244	111	161	161	279	134	190	166
245	104	159	161	280	151	182	166
246	102	[a]	161	281	191	166	167

[a] Invalid data

[b] Unit down

TABLE 17. SUMMARY OF HOURLY NO_x EMISSION DATA

Variable	Number of points	Mean	Standard deviation	Standard error of mean	Minimum value	Maximum value
NO_x Concentration, ppm						
North	1,374	194	16.1	0.436	116	240
South	1,264	196	15.9	0.446	129	255
NO_x Emissions, ng/J						
North	1,360	165	16.0	0.436	77	209
South	1,250	161	15.7	0.443	75	208
Average	1,363	163	15.8	0.420	76	209
NO_x Emissions, Percent of Standard (301 ng/J)	1,248	54.2	5.0	0.143	26	70
Boiler Load, MWe	1,469	129	41.5	1.08	61	266
Carbon Monoxide, ppm	1,358	62.8	41.0	1.11	32	475
O_2 Prior to Air Preheater, Percent	1,136	5.45	1.34	0.040	1.8	9.85
Excess Air, Percent	1,136	36.4	12.0	0.36	9.4	89.4
O_2 North, Percent	1,370	8.50	1.35	0.036	4.85	15.0
O_2 South, Percent	1,260	8.02	1.52	0.043	4.0	15.1
Secondary Air Flow, 1,000 lb/hr	1,134	1,550	326	9.7	995	7,159

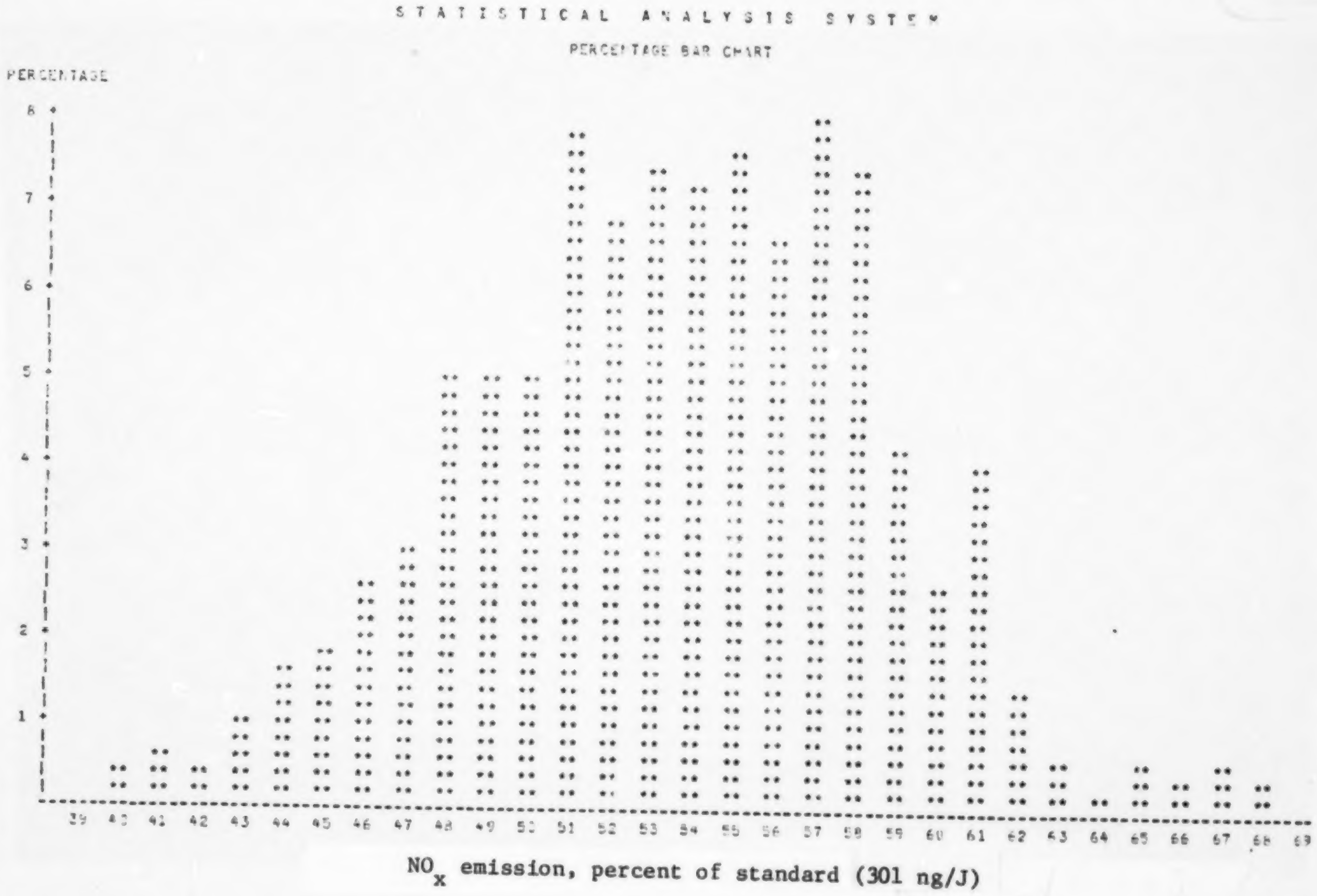

Figure 18. Frequency distribution for hourly NO_x emission rates.

Correlations Between NO_x Emission Rates and Process Parameters

The objective of this task was to develop statistically valid explanations for some of the observed variations in NO_x emission rates. Process parameters that were considered included boiler load, secondary air flow, excess air (or oxygen concentration prior to the air preheater), carbon monoxide concentrations, and oxygen concentrations at the scrubber inlet. During this phase of the program, possible physical or chemical explanations for the influence of process parameters were considered in choosing correlations to be investigated. For example, one might anticipate that increases in boiler load could increase NO_x emissions by increasing the temperature in portions of the boilers. Observed cross correlations between process parameters were also considered in the development of the final explanations for variations in NO_x emissions. For example, secondary air flow is highly correlated with boiler load and excess air or oxygen concentration so a choice was made between these parameters.

Multiple linear regression was selected as the primary data evaluation tool because of the amount of data and the lack of planned parametric experiments. Various combinations of many of the variables discussed above and listed in previous data tables were investigated in a backward stepwise linear regression process. Some examples and the final selected equation are discussed in the following paragraphs.

One of the early investigations focused on four variables--boiler load, secondary air flow, oxygen concentration before the air preheater, and carbon monoxide concentration. Of the four variables, load appeared to be the most significant, followed by carbon monoxide concentration, secondary air flow and oxygen concentration before the air preheater. Several forms for the linear regression were considered--linear and exponential terms and inverse relationships--but none were especially successful. Values for R squared were in the range of 0.26 to 0.31 with F values near 100. The R squared values indicate that 26 to 31 percent of the variation in NO_x emissions was explained by the developed regression equations. The F values indicate that the observed relationships were very unlikely to occur by chance (i.e., the developed equations and relationships were statistically significant).

However, further investigations were conducted to determine if an equation could be developed that would explain a greater percentage of the variations in NO_x emissions. The final equation that was selected is presented below:

$$NO_x = 27.8 + \underset{0.45}{12.4}\,(O_2) + \underset{0.014}{0.22}\,(\text{load}) - \underset{0.0084}{0.0495}\,(\text{CO, ppm}) \qquad (18)$$

where the values below the coefficients are the standard errors, and the variables are:

NO_x = average hourly NO_x emission rate, ng/J

O_2 = O_2 at the North tower inlet, %

Load = boiler load, MWe

CO = carbon monoxide concentration corrected to 0 percent excess air, ppm.

The value of R squared for the above equation is 0.52. It would have been preferred to use the oxygen concentration before the air preheater instead of the tower inlet because of the possible physical/chemical explanation; higher oxygen concentrations in the boiler could cause more oxidation of fuel and air nitrogen. However, the value of R squared for this alternative was only 0.26. In the selected equation, O_2 is the primary factor responsible for the observed variations in NO_x emissions, followed by load and CO.

The F value for the selected NO_x regression equation is very high, 491. One would expect that increased O_2 levels would increase NO_x emissions but a physical explanation for this influence of tower inlet O_2 is not available. Increased boiler loads may increase NO_x emissions as the temperature in parts of the boiler increases. Carbon monoxide could cause some chemical reduction of NO_x. Whether or not these potential explanations for the observed results are valid or not cannot be demonstrated with the availabile data.

The coefficients for the NO_x regression equation have small standard errors (listed below the equation) and large F values indicating that they are highly significant. Confidence intervals for the coefficients in the NO_x regression equation are

> 12.4 ± 0.88 for the O_2 coefficient, 0.22 ± 0.027 for the load coefficient and 0.0495 ± 0.016 for the CO coefficient.

At the mean oxygen, load and CO values of 8.50 percent, 129 MWE and 62.8 ppm, the 95 percent confidence interval for the predicted hourly NO_x emission value is 162 ± 11 ng/J.

Figure 19 presents a comparison of the measured NO_x emissions and the predicted emissions based on the developed regression equation. The equation does account for a significant part of the observed variations in NO_x emissions as shown by the tendency of the points to fall around the 45 degree line. If the R squared value for the equation was 1.0 instead of 0.52, all the points would fall on the 45 degree line.

The linear regression equation developed for the observed NO_x emissions data is very significant. The standard errors are small, the F values are high, and it does explain 52 percent of the observed variations in NO_x emissions. While it is desirable to be able to explain all the variations in NO_x emissions, it should be noted that the NO_x emissions were not highly variable; over 90 percent of the hourly results were in the 135 to 185 ng/J range. Thus the regression equation explains a reasonable percentage of the variations of a parameter that is not highly variable.

The O_2, boiler load, and CO hourly values under which the correlation was developed are illustrated in the frequency distributions presented in

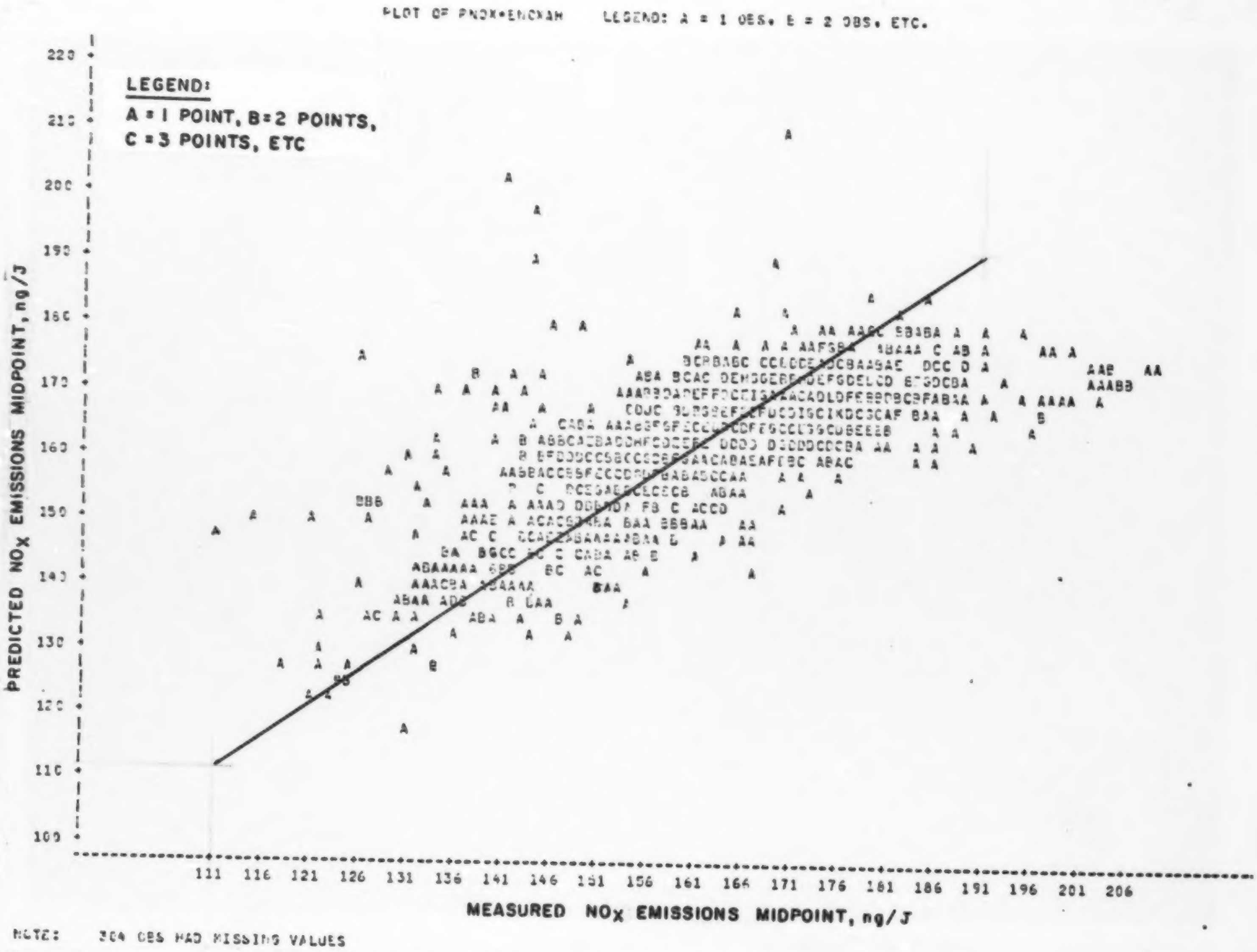

Figure 19. Comparison of measured and predicted hourly NO_x emissions.

Figures 20 to 22. These distributions should be considered when evaluating or using the linear regression equation. Specifically the form of the equation and coefficients are affected by the large amount of data at low loads, at O_2 concentrations in the 8 to 10 percent range and by CO concentrations in the 35 to 65 ppm range. Also, the regression applies only to operations at A. B. Brown because its physical/chemical basis is unknown and it does not include data from other sites.

Several factors could be responsible for the unexplained variations in NO_x emissions. Coal nitrogen content is known to affect NO_x emissions and probably contributed to the variations. The measurements may include some small errors that could contribute to variations in the observed emission rates. There could also be unknown factors that affect NO_x emissions.

SULFUR DIOXIDE

Emission Control Performance

The sulfur dioxide control system at A. B. Brown consists of two parallel FMC dual alkali scrubbers. The focus of this program is the performance of each individual module; not the combined performance on the total emissions from the plant. Daily averages for SO_2 emission rates, SO_2 collection efficiencies, and related data are presented in Table 18 for the north module and Table 19 for the south module. The mean efficiency for the north module was 88.0 percent while the mean efficiency for the south module was 86.5 percent. Mean SO_2 emission rates were 344 ng/J (0.80 lb/10^6 Btu) and 391 ng/J (0.91 lb/10^6 Btu) for the north and south modules, respectively.

Efficiencies for the north module averaged over 92 percent for seven days, while the south module daily average efficiency never exceeded 92 percent as shown in Figure 23. Three of the seven days that exceeded 92 percent efficiency occurred on the first five days of the program when the south module was shut down. High gas flow rates through the north module during these five days may be a contributor to the high efficiency. The efficiency of the north module averaged above 90 percent on 14 of 68 days while the south module exceeded 90 percent on only 4 of the 62 days.

Results for the observed 30-day rolling averages are presented in Table 20. North module rolling average efficiency was 90.5 percent for the first 30 days. It declined to 89.8 percent over the next 6 days and declined further towards the end of the program to 85.8 percent. The 30 day rolling averages for the south module efficiency followed a similar trend although the efficiencies were all lower. The highest south module rolling average efficiency of 86.6 percent was observed on the thirtieth day. Efficiencies declined to approximately 86 percent after 27 additional days and then more slightly to 85.3 percent at the end of the program. Decline in the rolling averages for SO_2 collection efficiency coincides with the reduction in average boiler load which was lower during the end of the test program.

Thirty day rolling averages for SO_2 emissions followed a similar pattern. North module 30 day rolling averages ranged from 274 ng/J (0.67 lb/10^6 Btu) to 396 ng/J (0.89 lb/10^6 Btu). South module rolling averages ranged from 355 ng/J (0.82 lb/10^6 Btu) to 418 ng/J (0.98 lb/10^6 Btu).

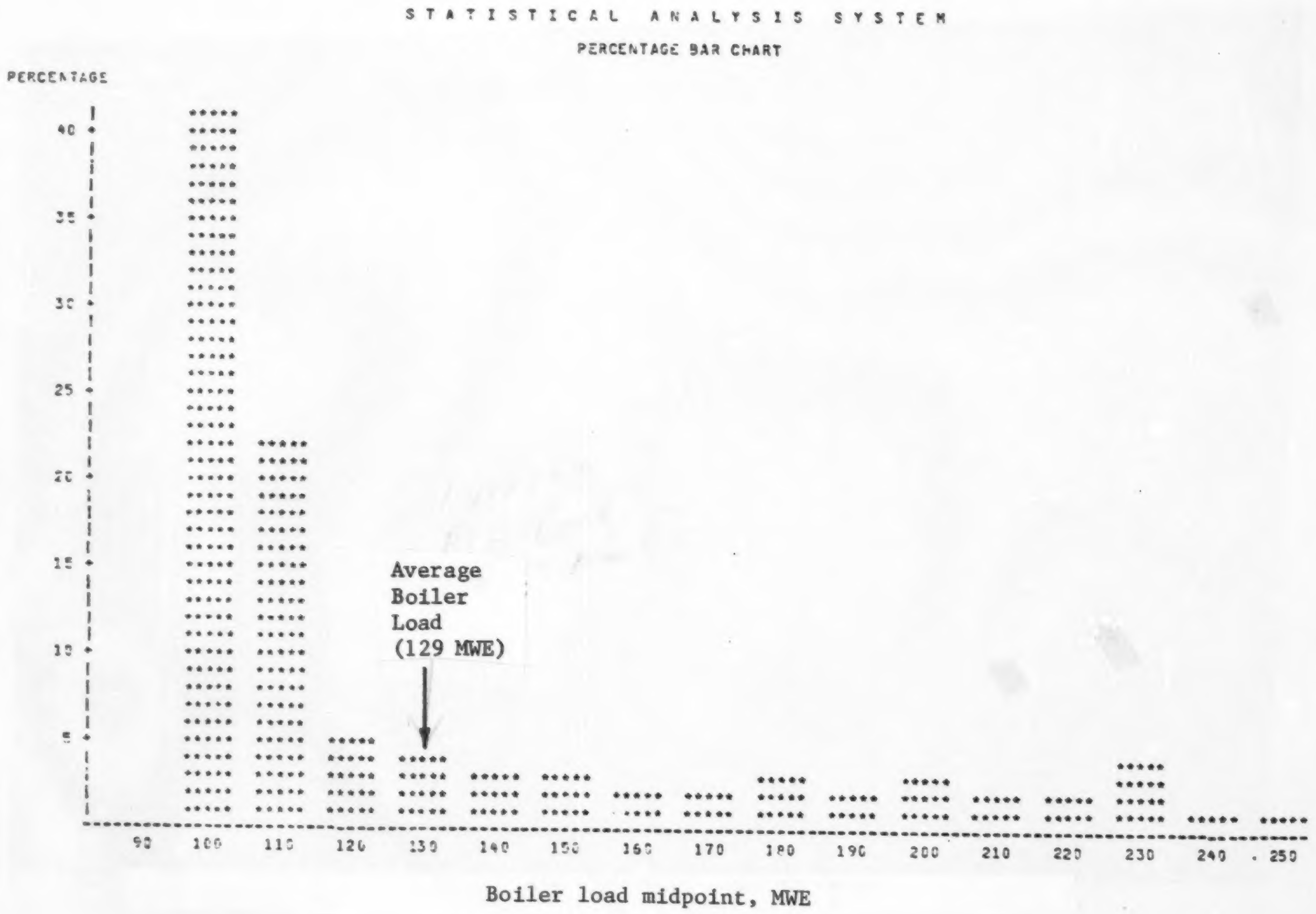

Figure 20. Hourly frequency distribution for boiler load.

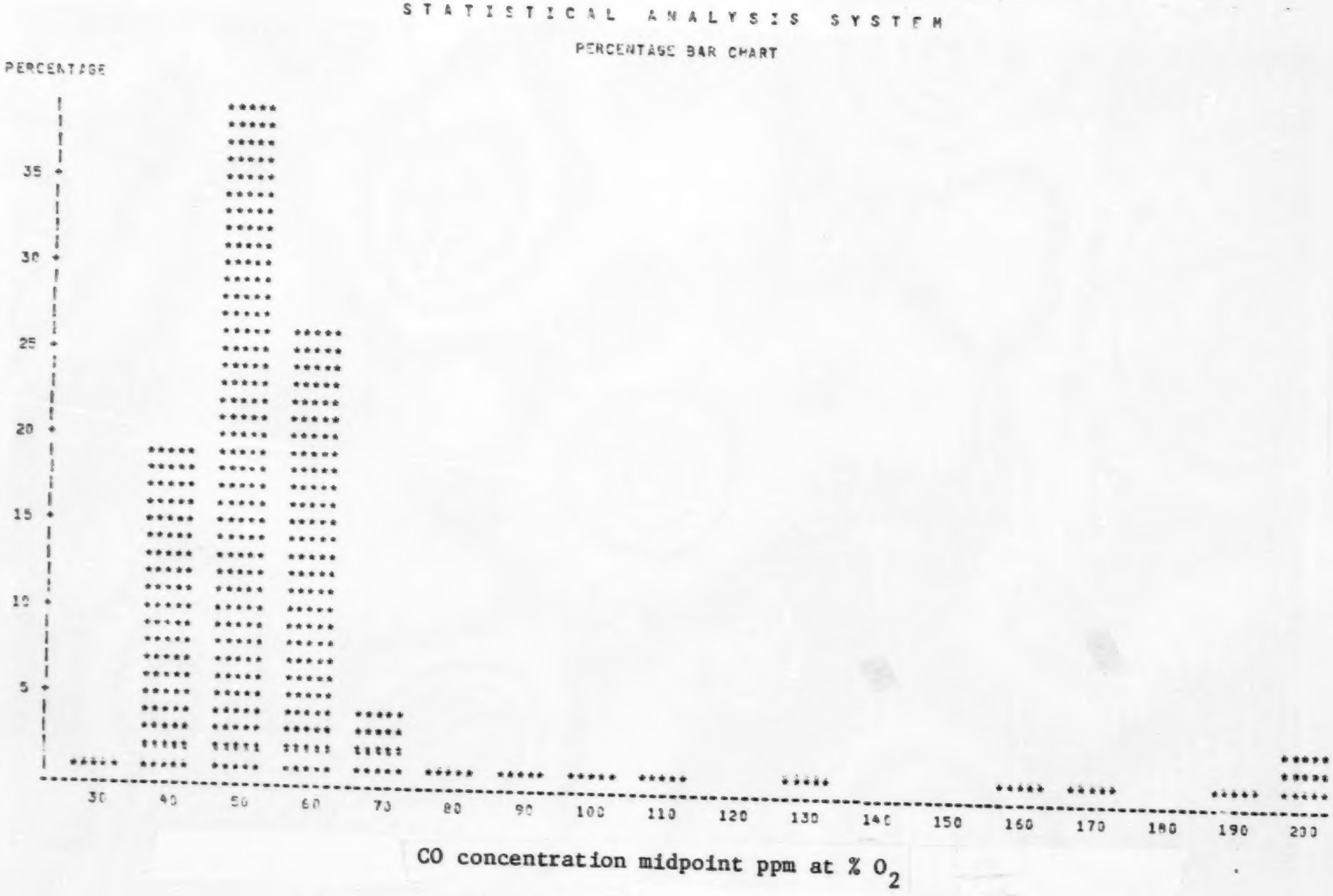

Figure 21. Hourly frequency distribution for corrected CO concentrations.

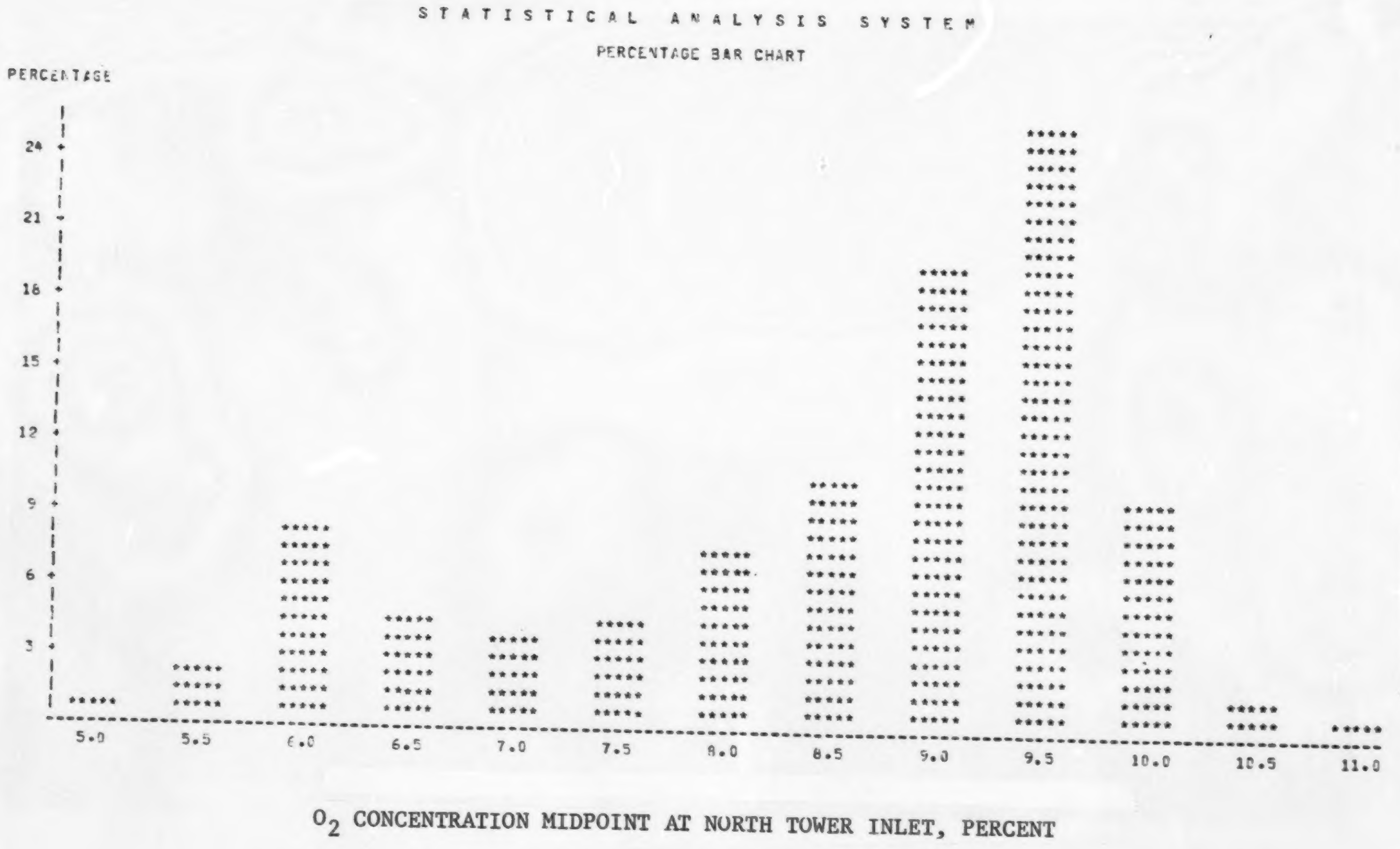

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Figure 22. Hourly frequency distribution for O_2 at north tower inlet.

TABLE 18. NORTH MODULE DAILY AVERAGES FOR SO_2

SCRUBBER SUMMARY - NORTH MODULE

DAILY DATA CEM DATA				INLET SO2			OUTLET SO2										
DAY	TIME	BLR LOAD (MWE)	EQUIV MOD LOAD MWE	SO2 PPM	%O2	E O2 NG/J	SO2 PPM	%O2	%CO2	F 0	E O2 NG/J	E CO2 NG/J	SO2 REMOVE EFF. (%)	TOWER PH	TOT REGEN FLOW (GPM)	LIME REACT PH	INLET OPAC (%)
212	0000	99	***	2427	8.01	2751	126	8.84	10.47	1.157	148	149	94.5	6.50	1005	7.00	3.3
213	0000	141	69	2725	7.29	2922	112	8.47	12.58	1.130	129	131	95.6	6.36	1299	3.85	3.4
214	0000	137	75	2499	8.26	2692	56	11.20	10.80	1.152	67	94	97.7	6.49	1265	8.01	3.3
215	0000	118	69	2329	8.81	2817	115	8.41	10.47	1.199	134	142	95.2	6.50	1326	7.50	3.1
216	0000	132	119	2459	8.24	2636	143	7.80	11.03	1.189	158	165	94.4	6.30	1592	7.05	3.2
217	0000	113	108	2253	6.50	2645	145	8.23	10.74	1.180	170	177	93.5	6.23	1692	7.55	3.3
218	0000	142	85	2395	7.67	2624	212	7.55	11.32	1.181	235	246	91.0	6.44	2196	6.90	3.9
219	0000	115	63	2417	7.77	2692	352	7.80	10.96	1.196	396	417	85.3	6.59	1539	7.14	3.4
220	0000	105	46	2282	8.38	2664	424	8.73	10.11	1.207	503	531	81.1	6.55	940	7.39	3.4
221	0000	104	59	2260	8.50	2665	303	8.51	10.36	1.197	357	376	86.6	6.51	1456	8.02	3.4
222	0000	160	77	2525	7.44	2738	213	7.42	11.55	1.170	237	245	91.3	6.38	1820	8.19	3.6
223	0000	121	64	2243	8.92	2735	234	8.88	10.27	1.174	288	298	89.4	6.32	1659	7.76	3.5
224	0000	134	73	2465	8.31	2684	[illegible]	8.41	10.66	1.176	241	250	91.6	6.48	1600	7.49	3.1
225	0000	181	68	2803	7.48	3049	276	7.87	11.34	1.151	315	320	89.6	6.41	1725	7.73	3.2
226	0000	178	60	2781	7.53	3042	244	7.94	11.23	1.155	273	278	91.0	6.21	2326	6.96	3.9
227	0000	101	59	2431	9.43	3093	209	9.32	10.25	1.207	258	300	93.0	6.51	2387	8.09	3.9
228	0000	102	66	2448	9.08	3028	205	8.82	10.05	1.201	247	262	91.3	6.50	1276	8.06	4.0
229	0000	112	70	2425	8.67	2899	204	8.46	10.54	1.181	239	249	91.7	6.46	2231	8.37	4.2
230	0000	173	86	2740	7.43	2970	166	7.24	11.76	1.164	182	187	93.8	6.41	2668	8.09	4.4
231	0000	173	87	2888	7.43	3148	273	7.27	11.78	1.158	293	298	90.6	6.42	2628	8.13	4.3
232	0000	178	103	2732	7.29	2933	233	7.18	12.02	1.144	252	253	91.4	6.34	2447	7.78	4.7
233	0000	166	103	2816	7.63	3096	202	7.17	11.91	1.156	211	214	93.2	6.47	2571	5.38	4.3
234	0000	131	81	2524	9.00	3100	203	8.60	10.50	1.174	242	251	92.2	6.34	1964	8.46	4.2
235	0000	143	82	2652	8.37	3093	277	8.06	11.03	1.166	323	332	89.5	6.42	2458	8.41	4.1
236	0000	209	92	2992	6.97	3141	306	6.67	12.47	1.143	314	316	90.0	6.41	2742	8.31	4.5
237	0000	177	106	2784	7.64	3070	224	7.35	11.79	1.151	242	246	92.1	6.40	2785	8.66	4.3
238	0000	129	70	2582	8.51	3047	326	8.76	10.35	1.172	398	406	86.9	6.45	1619	7.94	4.2
239	0000	106	71	2353	9.39	2990	298	9.23	9.85	1.185	372	388	87.5	6.57	1270	7.71	4.3
240	0000	109	93	2466	8.67	2948	268	8.65	10.39	1.180	322	335	89.0	6.44	2057	7.53	3.1
241	0000	141	96	2651	7.87	2977	271	7.76	11.32	1.162	306	310	89.7	6.41	2368	7.63	8.0
242	0000	142	***	2572	8.10	2939	336	7.94	11.04	1.176	373	386	87.3	6.41	2406	8.30	4.8
243	0000	139	***	2510	8.26	2898	393	8.28	10.60	1.194	464	489	83.9	6.41	2408	7.73	4.9
244	0000	111	***	2282	9.29	2872	374	9.09	9.70	1.219	465	500	83.8	6.47	2070	8.03	4.5
245	0000	104	***	2149	5.61	2784	344	9.32	9.49	1.221	434	467	83.9	6.51	1945	7.62	5.5
246	0000	102	***	****	*****	****	341	9.68	9.27	1.211	445	475	****	6.47	1737	7.30	17.8
247	0000	102	***	****	*****	****	381	9.78	9.23	1.207	506	538	****	6.36	1955	7.36	7.3
248	0000	112	***	2511	8.96	3075	416	9.23	10.09	1.163	524	537	84.9	6.34	2164	7.44	4.7
249	0000	99	***	2384	9.04	3099	318	9.67	9.88	1.156	410	418	86.7	6.39	1977	7.71	3.7
250	0000	123	***	2500	8.84	3035	317	8.74	10.48	1.163	383	391	87.4	6.43	2034	7.36	23.0
251	0000	156	***	2565	7.29	2773	294	7.86	11.27	1.162	332	341	87.9	6.38	2349	7.18	25.3

TABLE 18 (continued)

SCRUBBER SUMMARY - NORTH MODULE

DAILY DATA CEM DATA				INLET SO2			OUTLET SO2										
DAY	TIME	BLR LOAD (MWE)	EQUIV MOD LOAD MWE	SO2 PPM	%O2	E O2 NG/J	SO2 PPM	%O2	%CO2	F D	E O2 NG/J	E CO2 NG/J	SO2 REMOVE EFF. (%)	TOWER PH	TOT REGEN FLOW (GPM)	LIME REACT PH	INLET OPAC (%)
252	0000	153	***	2708	6.62	2785	243	7.94	11.50	1.128	274	272	89.3	6.50	2974	7.40	12.8
253	0000	167	***	2654	7.76	2955	224	7.66	11.58	1.137	244	244	91.7	6.49	3061	7.77	5.1
254	0000	191	***	2581	6.94	2699	260	7.09	12.19	1.136	277	277	89.7	6.24	2813	7.86	5.1
255	0000	117	***	2161	8.78	2600	244	8.73	10.54	1.155	283	293	89.1	6.40	2769	7.75	7.8
256	0000	109	***	2328	8.61	2614	258	8.69	10.41	1.173	345	356	87.7	6.47	2894	7.30	4.5
257	0000	157	***	2586	7.36	2793	299	7.39	11.65	1.155	325	332	88.3	6.45	3073	8.27	10.8
258	0000	114	***	2212	9.02	2721	239	8.97	10.19	1.157	298	302	89.1	6.52	1726	8.45	8.0
259	0000	122	***	2054	9.71	2683	277	9.64	9.54	1.180	360	374	86.6	6.50	1629	****	19.9
260	0000	100	***	2010	9.87	2663	296	9.67	9.48	1.185	386	402	85.5	6.45	2088	8.23	5.1
261	0000	97	***	1980	10.24	2718	299	10.01	9.23	1.185	402	418	85.2	6.42	2106	8.08	6.1
262	0000	***	***	****	*****	****	***	*****	*****	*****	***	***	****	****	****	****	****
263	0000	***	***	****	*****	****	***	*****	*****	*****	***	***	****	****	****	****	****
264	0000	98	43	2105	9.64	2732	306	10.23	8.57	1.247	418	459	84.7	6.28	1771	7.29	4.9
265	0000	106	***	2012	9.83	2657	340	9.71	9.35	1.197	443	467	83.3	6.29	2290	****	29.5
266	0000	106	75	2199	9.34	2780	349	9.25	10.03	1.162	438	448	84.2	6.41	1673	****	14.7
267	0000	119	91	2204	9.22	2757	328	9.10	10.09	1.326	409	486	85.1	6.45	1667	8.35	9.3
268	0000	109	103	2295	8.92	2799	337	8.81	10.32	1.172	407	420	85.4	6.46	1620	7.93	8.1
269	0000	107	116	2220	9.10	2749	310	8.85	10.18	1.184	376	392	86.3	6.44	2132	****	14.2
270	0000	106	72	2243	9.09	2775	327	8.93	10.22	1.172	399	411	85.6	6.46	1746	8.15	4.8
271	0000	108	74	2284	8.93	2788	361	8.80	10.49	1.154	436	444	84.3	6.50	1593	7.81	4.8
272	0000	120	79	2226	9.16	2769	317	9.04	10.20	1.163	394	404	85.7	6.53	1419	8.37	5.0
273	0000	143	81	2481	7.90	2788	399	7.70	11.42	1.158	441	449	84.2	6.53	1395	7.75	4.8
274	0000	126	79	2517	8.27	2911	413	8.10	10.92	1.174	474	491	83.6	6.44	1860	8.24	4.9
275	0000	105	69	2388	9.09	2956	436	9.17	10.13	1.158	544	555	81.6	6.44	1980	7.90	5.5
276	0000	105	59	2329	9.39	2946	405	9.59	9.74	1.196	524	546	82.2	6.50	1543	7.92	5.5
277	0000	101	71	2317	9.21	2898	413	9.21	10.11	1.156	517	525	82.1	6.49	1535	7.77	5.1
278	0000	156	***	2646	8.02	3003	385	8.07	11.16	1.151	442	448	85.2	6.47	2135	****	20.0
279	0000	134	***	2564	8.86	3153	349	8.78	10.47	1.158	422	430	86.3	6.38	2393	****	26.8
280	0000	151	***	2629	7.93	2957	324	7.95	11.51	1.129	373	370	87.1	6.32	2697	****	20.7
281	0000	191	87	2866	6.53	2917	353	6.82	12.70	1.110	365	356	87.4	6.19	2726	7.83	5.9

TABLE 19. SOUTH MODULE DAILY AVERAGES FOR SO_2

SCRUBBER SUMMARY - SOUTH MODULE

DAILY DATA CEM DATA				INLET SO2			OUTLET SO2										
DAY	TIME	BLR LOAD (MWE)	EQUIV MOD LOAD MWE	SO2 PPM	%O2	E O2 NG/J	SO2 PPM	%O2	%CO2	F D	E O2 NG/J	E CO2 NG/J	SO2 REMOVE EFF. (%)	TOWER PH	TOT REGEN FLOW (GPM)	LIME REACT PH	INLET OPAC (%)
212	0000	99	***	****	*****	****	***	*****	*****	*****	***	***	****	7.47	1005	7.00	****
213	0000	141	***	****	*****	****	***	*****	*****	*****	***	***	****	6.18	1299	3.85	****
214	0000	137	***	****	*****	****	***	*****	*****	*****	***	***	****	7.49	1265	8.01	0.4
215	0000	118	***	****	*****	****	***	*****	*****	*****	***	***	****	7.50	1326	7.50	0.0
216	0000	132	27	****	*****	****	***	*****	*****	*****	***	***	****	7.52	1592	7.05	****
217	0000	113	33	****	*****	****	***	*****	*****	*****	***	***	****	7.11	1892	7.55	0.1
218	0000	142	53	2483	7.25	2655	329	7.29	11.53	1.184	362	***	86.3	6.37	2196	6.90	****
219	0000	115	47	2536	7.32	2730	377	7.44	11.30	1.191	413	***	84.8	6.46	1539	7.14	9.6
220	0000	105	44	2379	7.92	2679	377	8.22	10.75	1.179	433	***	83.8	6.48	940	7.39	0.2
221	0000	104	54	2319	8.19	2667	254	8.25	10.64	1.189	293	***	88.9	6.47	1456	8.02	0.0
222	0000	160	73	2601	7.05	2745	204	7.10	11.80	1.173	218	***	92.0	6.39	1820	8.19	****
223	0000	121	78	2340	8.52	2763	181	8.55	10.41	1.187	216	***	92.2	6.46	1659	7.76	0.9
224	0000	134	84	2666	7.53	29[illegible]	298	7.68	11.29	1.176	330	***	88.6	6.50	1800	7.49	14.6
225	0000	181	56	3012	6.59	3077	363	6.98	12.14	1.149	382	***	87.6	6.57	1725	7.73	****
226	0000	178	52	2914	6.87	3036	339	7.25	11.82	1.157	365	***	88.1	6.48	2326	6.96	****
227	0000	101	60	2665	8.34	3102	338	8.25	10.50	1.205	392	***	88.8	6.44	2387	8.09	****
228	0000	102	29	2521	8.74	3031	286	8.73	10.39	1.206	343	***	88.1	6.51	1276	8.06	0.1
229	0000	112	39	2527	8.28	2927	281	8.33	10.59	1.190	328	***	88.7	6.42	2231	8.37	0.2
230	0000	173	70	2978	6.47	3017	287	6.61	12.22	1.159	299	***	90.1	6.44	26[illegible]8	8.09	6.0
231	0000	173	65	3007	6.58	3070	407	6.72	12.18	1.167	423	***	86.3	6.38	2628	8.13	22.3
232	0000	178	89	2858	6.63	2928	263	6.65	12.43	1.149	274	***	90.6	6.43	2447	7.78	36.3
233	0000	166	92	3064	6.38	3085	241	6.40	12.68	1.148	245	***	92.0	6.48	2571	8.38	35.6
234	0000	131	73	2644	8.44	3102	278	8.30	10.81	1.169	325	***	89.5	6.35	1964	8.46	23.4
235	0000	143	92	2811	7.56	3065	362	7.57	11.50	1.162	404	***	86.8	6.38	2458	8.41	****
236	0000	209	108	3165	5.95	3095	360	6.03	13.07	1.139	358	***	88.4	6.33	2742	8.31	****
237	0000	177	106	2952	6.82	3065	318	6.88	12.24	1.147	331	***	89.2	6.34	2765	8.66	****
238	0000	129	64	2738	7.80	3055	330	8.00	11.09	1.164	379	***	87.6	6.44	1619	7.94	****
239	0000	106	71	2534	8.56	3002	385	8.68	10.40	1.174	461	***	84.6	6.50	1270	7.71	6.6
240	0000	109	64	2425	8.91	2957	299	8.94	10.09	1.186	364	***	87.6	6.46	2057	7.53	9.1
241	0000	141	83	2638	7.84	2953	390	7.92	11.17	1.166	440	***	85.1	6.35	2368	7.63	32.6
242	0000	142	86	2660	7.55	2913	361	7.63	11.34	1.172	397	***	86.3	6.39	2406	8.30	****
243	0000	139	80	2548	8.02	2892	413	8.15	10.62	1.202	484	***	83.2	6.43	2438	7.73	****
244	0000	111	73	2436	8.45	2660	401	8.51	10.16	1.235	477	***	83.3	6.39	2070	8.03	43.8
245	0000	104	72	2330	8.78	2810	413	8.74	10.08	1.207	496	***	82.5	6.49	1945	7.62	24.3
246	0000	102	71	****	*****		422	8.99	9.94	1.193	523	***	****	6.43	1737	7.30	36.1
247	0000	102	69	****	*****		487	8.98	10.06	1.186	600	***	****	6.34	1955	7.36	39.1
248	0000	112	60	2776	7.84	3107	421	8.42	10.88	1.148	493	***	84.2	6.46	2104	7.44	15.1
249	0000	99	60	2612	8.65	3117	395	8.84	10.53	1.146	478	***	84.6	6.46	1977	7.71	24.9
250	0000	123	60	2729	7.81	3048	386	7.95	11.28	1.148	438	***	85.6	6.42	2034	7.36	19.0
251	0000	158	55	2688	6.73	2773	411	7.27	11.86	1.152	441	***	83.7	6.38	2349	7.16	18.6

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TABLE 19 (continued)

SCRUBBER SUMMARY - SOUTH MODULE

DAILY DATA CEM DATA				INLET SO2			OUTLET SO2										
DAY	TIME	BLR LOAD (MWE)	EQUIV MOD LOAD MWE	SO2 PPM	%O2	E O2 NG/J	SO2 PPM	%O2	%CO2	F D	E O2 NG/J	E CO2 NG/J	SO2 REMOVE EFF. (%)	TOWER PH	TOT REGEN FLOW (GPM)	LIME REACT PH	INLET OPAC (%)
252	0000	153	60	2770	6.15	2745	315	7.09	12.14	1.139	333	***	86.2	6.37	2974	7.40	22.7
253	0000	167	69	2860	6.68	2940	311	6.90	12.31	1.137	328	***	86.9	6.35	3061	7.77	24.1
254	0000	191	60	2742	5.99	2688	355	6.58	12.53	1.146	365	***	86.3	6.35	2613	7.86	25.0
255	0000	117	70	2286	8.08	2607	311	8.32	10.73	1.166	359	***	86.2	6.35	2789	7.75	20.4
256	0000	109	57	2409	8.32	2759	381	8.58	10.44	1.180	451	***	83.8	6.27	2694	7.30	25.0
257	0000	157	85	2726	6.55	2777	350	7.00	12.00	1.161	373	***	86.5	6.31	3073	8.27	21.7
258	0000	114	73	2325	8.55	2752	293	8.78	10.38	1.169	355	***	87.1	6.54	1726	8.45	22.4
259	0000	122	96	2146	9.25	2693	337	9.45	9.66	1.186	429	***	84.0	6.53	1629	****	13.1
260	0000	100	51	2125	9.30	2678	346	9.51	9.58	1.182	446	***	83.3	6.45	2088	6.23	25.0
261	0000	97	52	2083	9.72	2724	356	9.63	9.62	1.177	461	***	83.0	6.45	2106	8.08	25.0
262	0000	***	***	****	*****	****	***	*****	*****	*****	***	***	****	****	****	****	****
263	0000	***	***	****	*****	****	***	****	*****	*****	***	***	****	****	****	****	****
264	0000	98	35	2251	8.94	2751	***	9.32	9.45	1.227	***	***	****	6.41	1771	7.29	25.0
265	0000	106	***	2121	9.37	2669	359	9.35	9.70	1.191	454	***	83.1	6.47	2290	****	12.4
266	0000	106	65	2240	9.12	2780	370	9.18	10.10	1.160	462	***	83.3	6.48	1873	****	12.0
267	0000	119	81	2218	9.07	2741	342	9.00	10.32	1.154	424	***	84.5	6.48	1667	8.35	14.3
268	0000	109	99	2298	8.90	2799	338	8.81	10.34	1.170	408	***	85.4	6.48	1820	7.93	16.3
269	0000	107	112	2236	9.09	2766	298	8.86	10.18	1.183	362	***	86.9	6.48	2132	****	12.6
270	0000	136	34	2262	9.02	2783	315	8.87	10.27	1.172	382	***	86.3	6.48	1746	6.15	25.2
271	0000	108	29	2340	8.65	2792	357	8.56	10.71	1.153	424	***	84.8	6.47	1593	7.81	25.0
272	0000	120	40	2255	9.04	2760	306	9.32	9.86	1.177	388	***	86.0	6.46	1419	8.37	23.8
273	0000	143	63	2441	8.04	2775	312	8.40	10.71	1.170	368	***	86.7	6.41	1395	7.75	23.6
274	0000	126	82	2629	7.87	2950	335	8.22	10.78	1.179	385	***	86.8	6.39	1860	8.24	23.9
275	0000	105	70	2467	8.95	3018	414	9.03	10.19	1.164	510	***	83.1	6.43	1960	7.90	19.4
276	0000	105	66	2436	9.04	3003	395	9.12	10.16	1.160	490	***	83.5	6.50	1543	7.92	21.6
277	0000	101	70	2439	8.66	2913	404	8.82	10.32	1.171	469	***	83.2	6.47	1535	7.77	24.3
278	0000	156	***	2666	7.77	2968	336	8.07	11.13	1.155	388	***	86.8	6.39	2135	****	12.6
279	0000	134	***	2430	8.88	2955	308	9.03	10.29	1.154	380	***	87.1	6.42	2393	****	5.6
280	0000	151	***	2677	7.93	3017	310	8.12	11.32	1.131	358	***	87.8	6.38	2697	****	7.4
281	0000	191	83	2934	6.37	2952	319	6.66	12.75	1.119	318	***	89.1	6.36	2726	7.83	19.1

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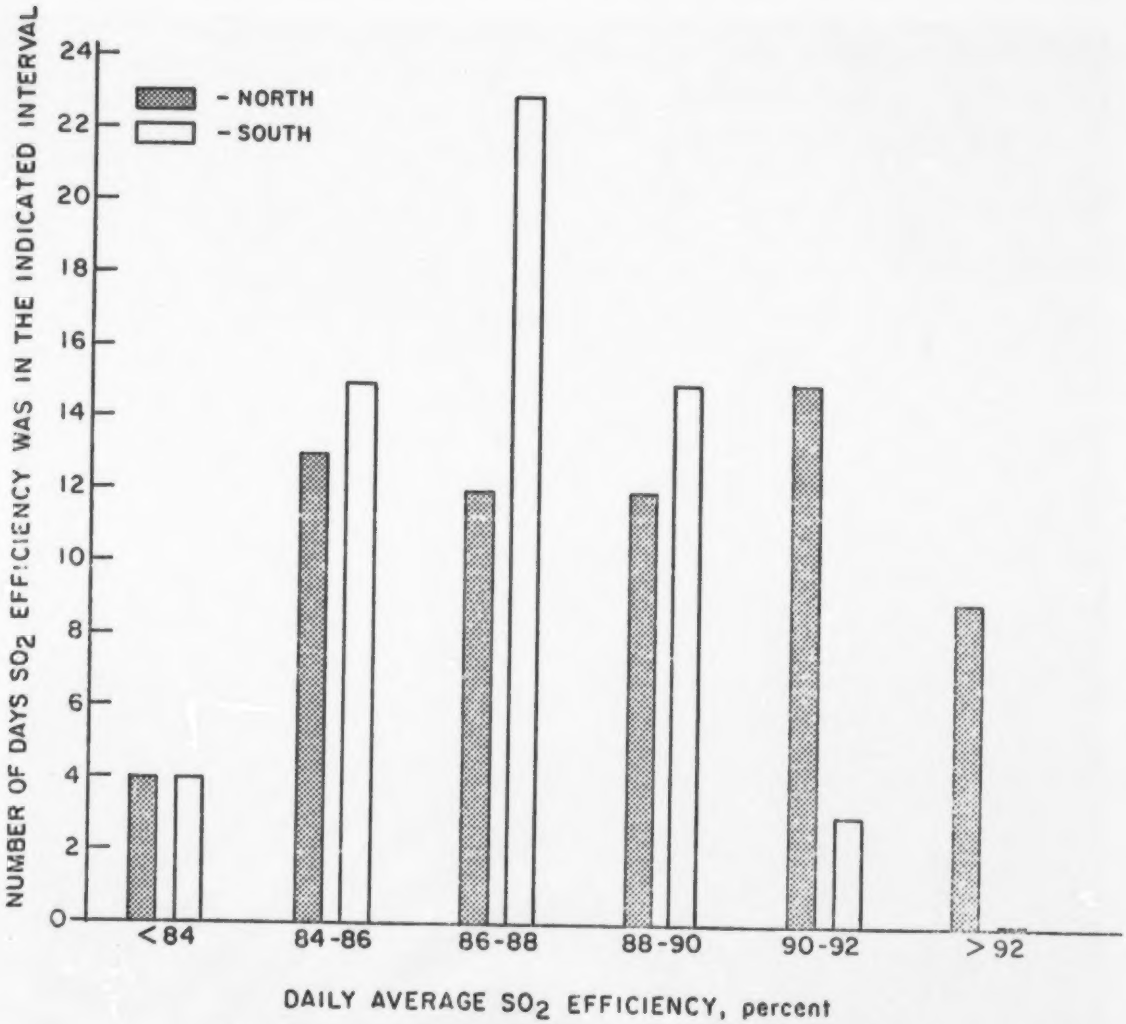

Figure 23. Frequency distribution of SO_2 daily averages.

TABLE 20. SO_2 PERFORMANCE: DAILY AND 30-DAY ROLLING AVERAGE

		North tower				South tower			
		Outlet Emissions (ng/J)		Removal Efficiency (%)		Outlet Emissions (ng/J)		Removal Efficiency (%)	
Day	BLR Load (MWE)	Daily	30-day Rolling	Daily	30-day Rolling	Daily	30-day Rolling	Daily	30-day Rolling
212	99	148	0	94.5	0	***[b]	0	****	0
213	141	129	0	95.6	0	***[b]	0	****	0
214	137	67	0	97.7	0	***[b]	0	****	0
215	118	134	0	95.2	0	***[b]	0	****	0
216	132	158	0	94.4	0	***[b]	0	****	0
217	113	170	0	93.5	0	***[b]	0	****	0
218	142	235	0	91.0	0	362	0	86.3	0
219	115	396	0	85.3	0	413	0	84.8	0
220	105	503	0	81.1	0	433	0	83.8	0
221	104	357	0	86.6	0	293	0	88.9	0
222	160	237	0	91.3	0	218	0	92.0	0
223	121	288	0	89.4	0	216	0	92.2	0
224	134	241	0	91.6	0	330	0	88.6	0
225	181	315	0	89.6	0	382	0	87.6	0
226	178	273	0	91.0	0	365	0	88.1	0
227	101	258	0	93.0	0	392	0	88.8	0
228	102	247	0	91.3	0	343	0	88.1	0
229	112	239	0	91.7	0	328	0	88.7	0
230	173	182	0	93.8	0	299	0	90.1	0
231	173	293	0	90.6	0	423	0	86.3	0
232	178	252	0	91.4	0	274	0	90.6	0
233	166	211	0	93.2	0	245	0	92.0	0
234	131	242	0	92.2	0	325	0	89.5	0
235	143	323	0	89.5	0	404	0	86.8	0
236	209	314	0	90.0	0	358	0	88.4	0
237	177	242	0	92.1	0	331	0	89.2	0
238	129	398	0	86.9	0	379	0	87.6	0
239	106	372	0	87.5	0	461	0	84.6	0
240	109	322	0	89.0	0	364	0	87.6	0
241	141	306	274	89.7	90.5	440	355	85.1	88.0
242	142	373	278	87.3	90.4	397	357	86.3	87.9
243	139	464	283	83.9	90.2	484	359	83.2	87.8
244	111	465	286	83.8	90.1	477	360	83.3	87.7
245	104	434	297	83.9	89.9	496	366	82.5	87.7
246	102	445	304	****	89.8	523	370	****	87.7
247	102	506	313	****	89.6	600	375	****	87.7

(continued)

TABLE 20 (continued)

		North tower				South tower			
		Outlet Emissions (ng/J)		Removal Efficiency (%)		Outlet Emissions (ng/J)		Removal Efficiency (%)	
Day	BLR Load (MWE)	Daily	30-day Rolling	Daily	30-day Rolling	Daily	30-day Rolling	Daily	30-day Rolling
248	112	524	320	84.5	89.5	493	377	84.2	87.8
249	99	410	319	86.7	89.7	478	378	84.6	87.9
250	123	383	321	87.4	89.5	438	380	85.6	87.8
251	158	332	319	87.9	89.7	441	383	83.7	87.7
252	153	274	320	89.3	89.6	353	386	86.2	87.5
253	167	244	318	91.7	89.7	328	384	88.9	87.6
254	191	277	319	89.7	89.6	365	386	86.3	87.5
255	117	283	318	89.1	89.6	359	385	86.2	87.4
256	109	345	320	87.7	89.5	451	388	83.8	87.3
257	157	325	322	88.3	89.5	373	387	86.5	87.2
258	114	298	324	89.1	89.4	355	387	87.1	87.2
259	122	360	326	86.6	89.4	429	389	84.0	87.2
260	100	386	333	85.5	89.0	446	394	83.3	86.9
261	97	402	336	85.2	88.8	461	395	83.0	86.8
262	***[a]	***	***	****	***	***	***	****	****
263	***[a]	***	***	****	***	***	***	****	****
264	98	418	347	84.7	88.4	***	407	****	86.3
265	106	443	352	83.3	88.1	454	409	83.1	86.1
266	106	438	357	84.2	87.8	462	413	83.3	85.8
267	119	409	363	85.1	87.4	424	417	84.5	85.6
268	109	407	364	85.4	87.4	408	418	85.4	85.5
269	107	376	364	86.3	87.3	362	414	86.9	85.6
270	106	399	367	85.6	87.1	382	415	86.3	85.6
271	108	436	372	84.3	86.9	424	414	84.8	85.5
272	120	394	373	85.7	86.8	388	414	86.0	85.5
273	143	441	375	84.2	86.7	368	412	86.7	85.6
274	126	474	378	83.6	86.6	385	412	86.8	85.6
275	105	544	382	81.6	86.3	510	413	83.1	85.4
276	105	524	389	82.2	86.1	490	414	83.5	85.4
277	101	517	393	82.1	85.9	489	413	83.2	85.3
278	156	442	392	85.2	85.9	388	412	86.8	85.3
279	134	422	395	86.3	85.8	380	410	87.1	85.4
280	151	373	395	87.1	85.8	358	407	87.8	85.4
281	191	365	396	87.4	85.8	318	405	89.1	85.4

[a] Unit offline

[b] Scrubber module offline

0 - Not applicable

*** - Missing data

Concentrations of $SO_3^=$ and HSO_3^- were measured by SIGECO's laboratory during the test program. Average concentrations in the regenerated liquor were about 0.33 mole/liter for $SO_3^=$ and 0.03 mole/liter for HSO_3^-. The total regenerated liquor flow, which is divided between the two modules, averaged 2042 gal/min.

SIGECO also analyzed the filter cake during the test program. Typically the cake contained about 50 percent moisture and less than 0.05 percent chlorides. Sodium in the filter cake averaged below 3 percent. Comparison of the sodium to the sulfur in the filter cake indicates less than 0.05 mole of Na_2 per mole of SO_2 collected. This later figure is an indication of sodium consumption although leaks may be responsible for significant additional losses.

Hourly data including some descriptive statistics are summarized in Table 21. The data show that the mean SO_2 efficiency for the north tower was significantly higher than for the south tower and that the outlet SO_2 emissions followed the same pattern. These differences in performance might be attributable to the differences in gas flow; or other variables including the fact that the south module did not operate for the first 5 days of the program.

Hourly SO_2 efficiencies are described further in Figures 24 and 25. The frequency distribution in Figure 24 shows that 32 percent of the north scrubber hourly SO_2 efficiencies were above 90 percent, 50 percent were between 85 and 90 percent, and 18 percent were below 85 percent efficiency. Figure 25 indicates that the south tower operated at hourly efficiencies over 90 percent for about 19 percent of the total hours; efficiencies in the 85 to 90 percent range were observed 54 percent of the hours and efficiencies below 85 percent occurred 27 percent of the time.

Frequency distributions for hourly SO_2 emission rates are presented in Figures 26 and 27. The data show that emissions from the north tower exceed 516 ng/J during about 5 percent of the hours, while the south tower exceeds 516 ng/J about 8 percent of the hours. In addition, the south tower shows 1.6 percent of the hours above 640 ng/J.

The tower pH is controlled at 6.5 and the data show that on an average this value is achieved. Lime reactor pH averaged 8.1. Average boiler load during the test series was 129 MWe, and the average oxygen concentrations at the tower inlets were 8.5 percent and 8.0 percent for the north and south modules, respectively.

Correlations Between SO_2 Control Performance and Process Parameters

The objective of this task was to develop statistically valid explanations for the observed variations in SO_2 control efficiencies and SO_2 emission rates. It was hoped that such explanations would point out methods to maintain higher efficiencies than those actually measured during the test program. As previously discussed, the efficiency of the north tower exceeded 90 percent for 32 percent of the hours. Successful correlations

TABLE 21. SUMMARY OF HOURLY SO_2 DATA

Variable	Number of points	Mean	Standard deviation	Standard error of mean	Minimum value	Maximum value
Inlet SO_2 rate, ng/J						
North	1,368	2,954	271	7.3	2,174	4,124
South	1,256	2,959	224	6.3	1,489	3,934
Inlet SO_2 concentration, ppm						
North	1,369	2,505	343	9.3	1,634	3,476
South	1,258	2,613	380	10.7	1,533	3,643
Outlet SO_2 emissions, ng/J						
North	1,465	344	92	2.8	29	662
South	1,344	391	62	2.6	102	887
SO_2 efficiency, percent						
North	1,367	88.0	3.3	0.094	75.9	99.0
South	1,250	86.5	2.2	0.084	71.2	96.7
Outlet gas flow, acfm						
North	864	239	79	2.7	19	419
South	1,118	202	83	2.5	16	419
Tower pH						
North	1,469	6.446	0.145	0.0038	5.60	7.46
South	1,458	6.512	0.295	0.0077	4.8	8.2
Regenerated liquor flow, gpm	1,469	2,042	626	16	2	3,454
Lime reactor pH	1,112	8.101	0.700	0.021	2.78	9.98
Boiler load, MWe	1,469	129	42	1.1	61	266

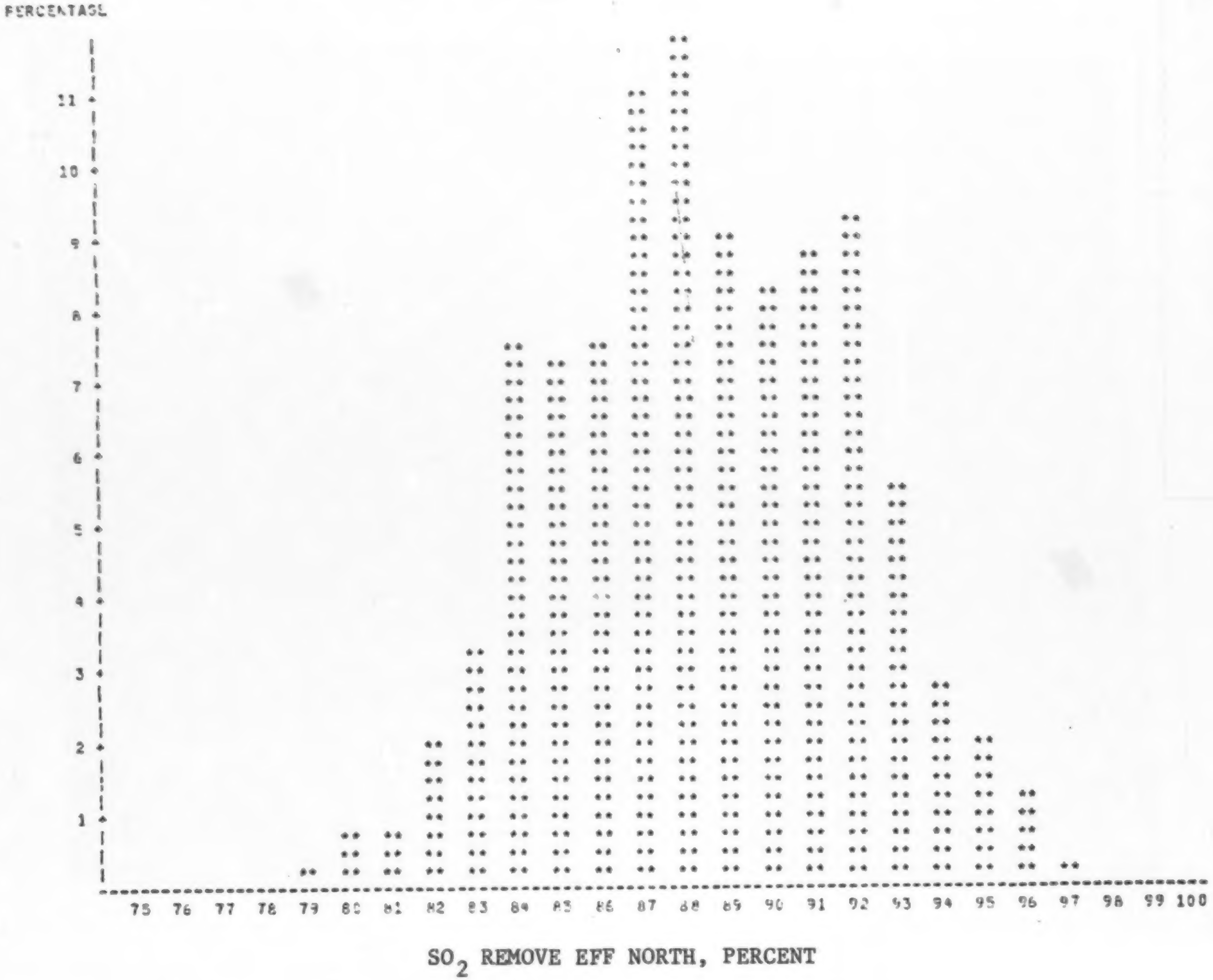

Figure 24. Frequency distribution for north tower hourly efficiencies.

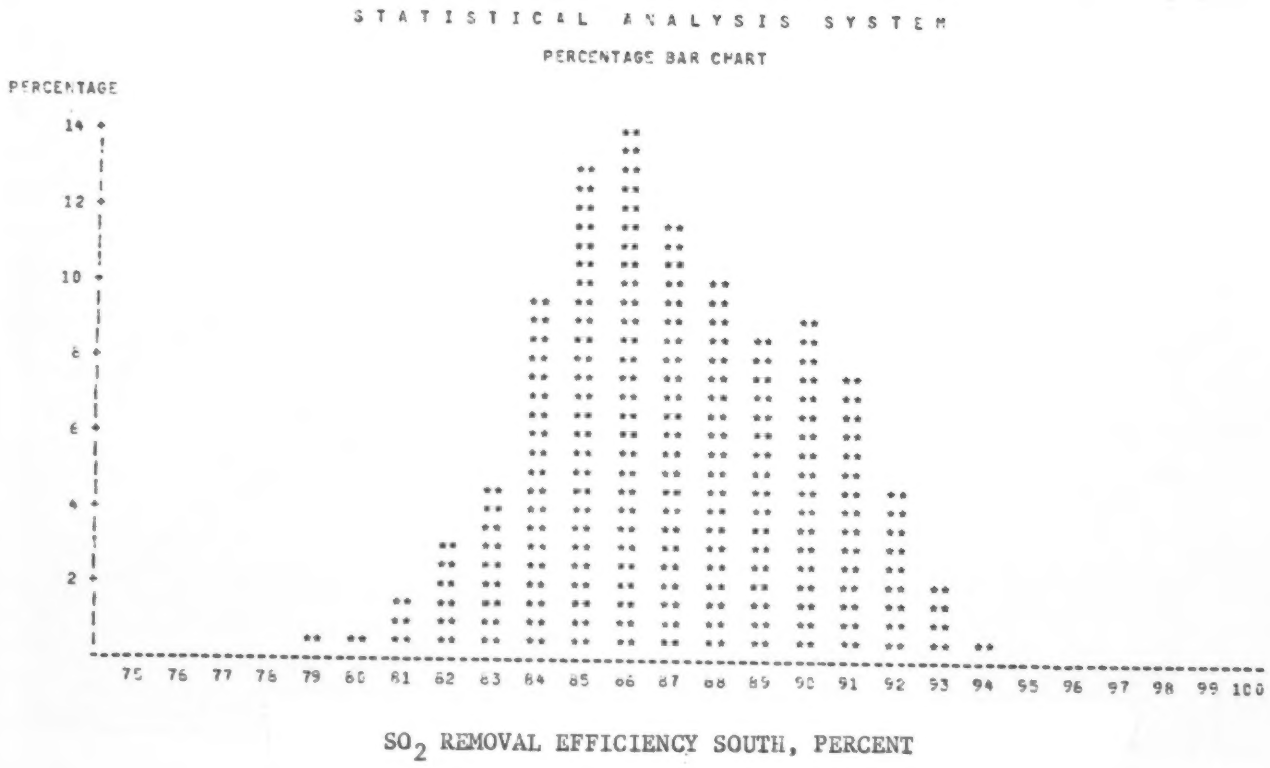

Figure 25. Frequency distribution for south tower hourly efficiencies.

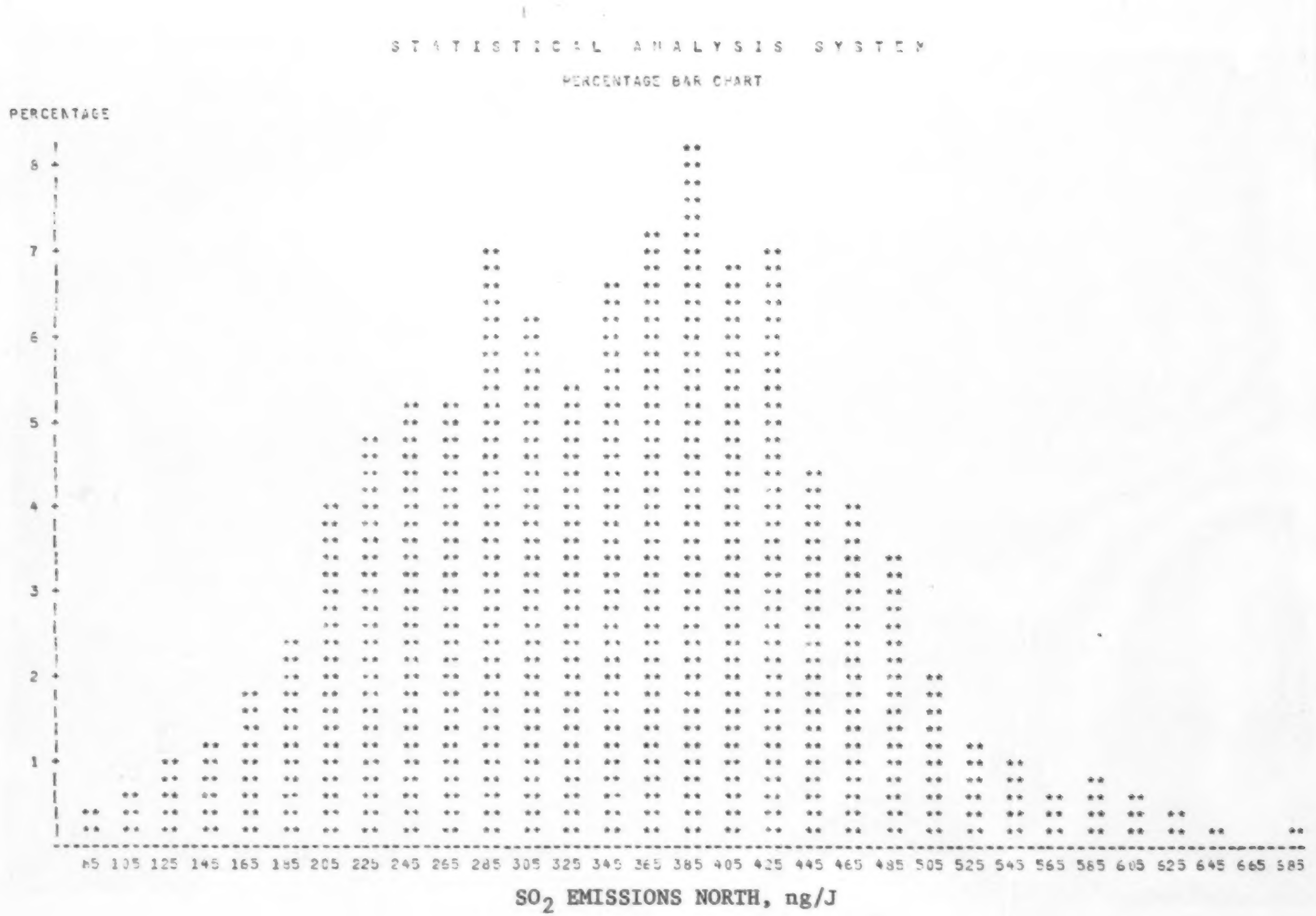

Figure 26. Frequency distribution of hourly SO_2 emissions for the north tower.

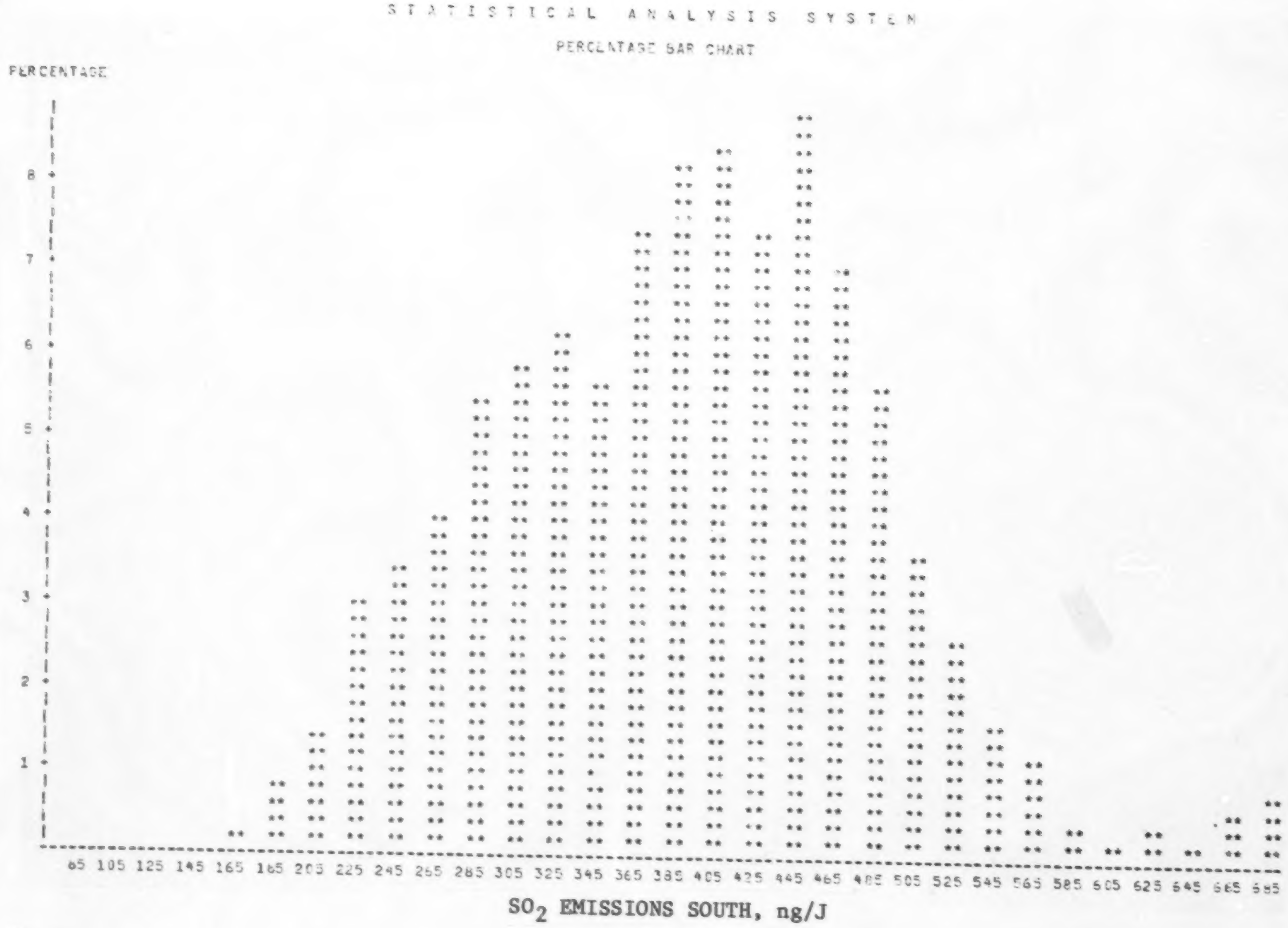

Figure 27. Frequency distribution of hourly SO_2 emissions for the south tower.

might indicate methods to achieve greater than 90 percent efficiency for a larger percentage of the hours. Prior to the test program, it was anticipated that gas flow through each tower would have the strongest effect on efficiency.

Variables that were investigated were boiler load, inlet SO_2 concentration, inlet SO_2 emission rate, tower pH, regenerated liquor flow, lime reactor pH, inlet opacity, and gas flow. Several forms for the regression analysis were used, including linear, exponential, and inverse relationships. The best equation that could be developed, as discussed in the following paragraphs, explained greater than 92 percent of the variations in SO_2 removal efficiency.

The development of correlations between SO_2 control (efficiency) and process parameters was approached using Venturi scrubber models as background information. According to these models, the main variable which affects collection efficiency is liquid droplet surface area. The surface area is directly proportional to the flue gas velocity. The higher the gas velocity, the smaller the drop size and consequently, the larger the surface area associated with an atomized volume of liquid.

Similarly, FMC's tower design depends on velocity for atomization. Consequently, these towers are expected to exhibit higher collection efficiencies at full load conditions.

Collection efficiencies for both towers were affected by gas flow only as shown by the equations shown below:

North module:

$$\begin{aligned} \text{eff} &= 6.4\text{X}10^{-7}\ (\text{flow})^{2.5} - 3.4\text{X}10^{-6}\ (\text{flow})^{3.5} \\ &\quad + 4.7\text{X}10^{-9}\ (\text{flow})^{4.5} \\ R^2 &= 0.9814 \text{ for } N = 530 \end{aligned} \tag{19}$$

South Module:

$$\begin{aligned} \text{eff} &= 1\text{X}10^{-3}\ (\text{flow})^{2.5} - 6.3\text{X}10^{-6}\ (\text{flow})^{3.5} \\ &\quad + 1.0\text{X}10^{-8}\ (\text{flow})^{4.5} \\ R^2 &= 0.9280 \text{ for } N = 506 \end{aligned} \tag{20}$$

where eff is the percent sulfur removal efficiency, %

flow is the gas flow rate at standard conditions, 10^3 a ft^3/min

R^2 = correlation coefficient

N = number of data points analyzed

These equations describe greater than 92 percent of the process variation for the data segment analyzed. It should be noted, however, that these correlations may only be indicative of the data set obtained from this test site and may not represent performances to be exhibited by other dual-alkali systems.

As long as the pH of the systems is in tolerance, the variation of control performance is only a function of gas flowrate. In the FMC system, the scrubbants are highly buffered and automatically regenerated. In addition, the liquid circulation rate is held constant through the tower and regenerated automatically as required.

Figure 28 shows a plot of SO_2 removal efficiency as a function of gas flow rate. As shown by the figure, the removal efficiency is only affected by the gas flow rate through the tower as long as the pH of the system is within the design tolerances. According to the data set, and the extrapolation of the curve, one can expect a removal efficiency approaching 90 percent at a gas flow rate of 400,000 a ft^3/min. As stated above, this plot depicts a trend in the data and should not be applied to other dual alkali scrubber systems.

No equations were generated to describe outlet emission performance, since the equations describing efficiency can also be rearranged to describe outlet emissions rates.

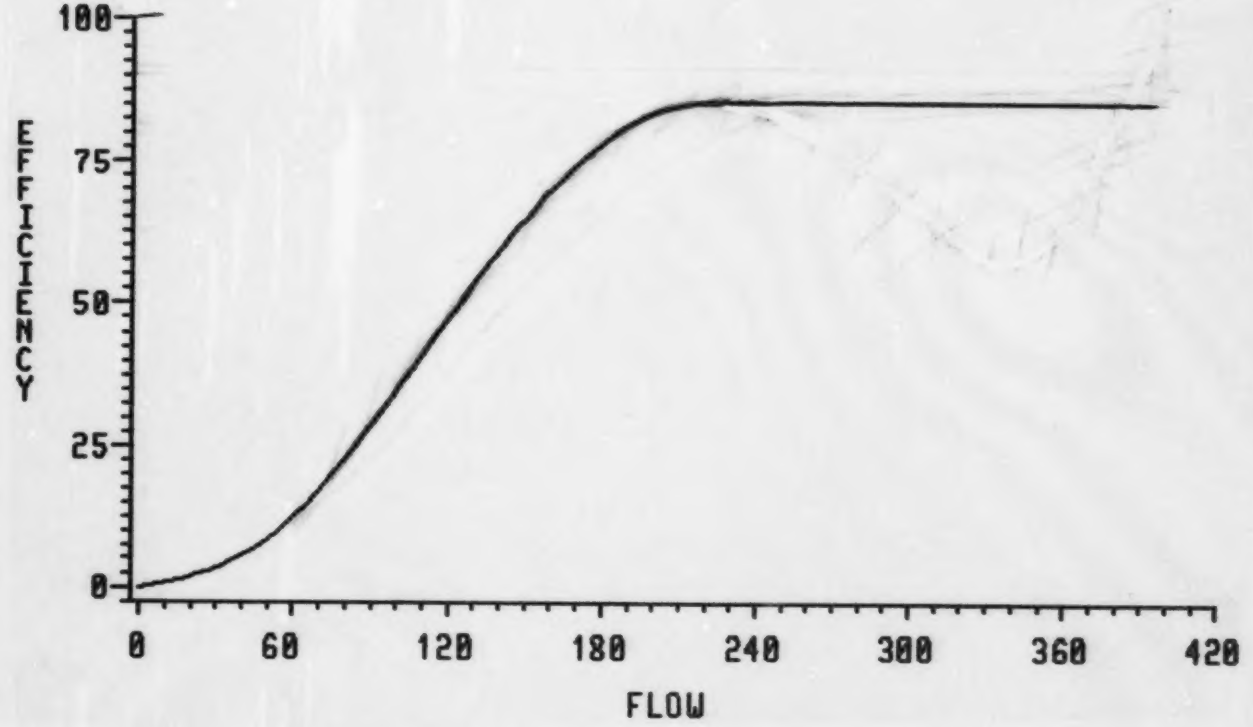

Figure 28. Plot of gas flow rate as a function of SO_2 removal efficiency.

SECTION 6

MEASUREMENT SYSTEM RESULTS

OPERATIONAL EXPERIENCE

Startup

The mobile laboratory was transported to the test site and parked for setup on May 20, 1981. At that time, it was anticipated that setup and checkout would require approximately one month. Subsequently, a week was scheduled for the performance specification tests which are designed to assess and certify the performance of the monitoring system.

Actual startup and commencement of the monitoring portion of the program required an additional 6 weeks of troubleshooting and equipment checkout. As a result, the monitoring system was not ready for performance testing as originally scheduled. There were two main problems which were identified but reoccurred quite frequently until the proper modifications were performed and verified. These problems involved a spurious voltage induction into the analytical electronics/data processing system and frequent leakage due to heat trace line flowing and valve diaphram ruptures.

The voltage induction problem was initially perceived as instrument drift on the inlet and outlet SO_2 and O_2 analyzers. Initially, these four analyzers were operated on a 10 mV output range and the strength of the random voltage was on the order of 1 to 2 mV. To rectify this problem, the analyzer output ranges were expanded to at least 100 mV and the instruments were wired to the data acquisition system using shielded cable. With these expanded ranges, the presence of 1 mV noise level would be much less significant than before.

Frequent leakage was the other problem which delayed startup significantly. As shown in Figure 14, the system was configured to sample multiple locations. The cycling mechanisms which consisted of diaphragm valves were a common source of leakage. These valve problems were finally rectified by lowering the operating temperature of the extraction boxes and utilizing gasket sealant between valve diaphrams and metal surfaces. The manufacturer had not previously seen the leakage and failure rate of these types of valves due to the fact that the valve is normally not operated as frequently as this application required. Also, the operating temperature (e.g. 290°F) was close to the upper temperature specification range for the component.

Other leaks surfaced randomly at different connection points within the extraction system. The most prevalent point was at heat traced sample line junction points. In most cases, the tubing would shrink and a leak would develop around the Swagelok ferrule. Machined inserts were finally utilized to correct this problem.

The previous discussions of problems can be designated as normal startup. Although the system is designated as a mobile facility, it was the first test program following fabrication. From experience on past programs, it normally required a two-month period for startup and debugging for a system as complex as the mobile laboratory. Subsequent tests are expected to entail two to four weeks setup, depending on the sampling strategy being employed. Many of the startup problems were attributed to a newly fabricated system which required a break in period and a familiarization by project personnel.

Routine Operation

During the A. B. Brown monitoring program approximately 68 days of data were collected. Throughout this program very little data loss was attributed to hardware problems after the rectification of the initial startup problems. Table 22 contains a listing of the data availability and system availability. The continuous monitoring system for this discussion is sub-divided into the categories of measurement hardware which includes the extraction-conditioning system and sensors and data acquisition which includes the primary computer system and the back up data logger. Measurement hardware demonstrated an availability of at least 96 percent (based on number of hours). Downtime was experienced during August due to an inlet pump failure. The majority of the problems were experienced with the primary computer system as indicated by the average 65 percent computer data capture rate shown in the table. This problem was identified near the end of the program as being a system software design problem which would be corrected by John FLUKE Company as soon as we could send it back to the service center. Because the control link portion of the computer was being utilized to operate the cycling valves and condensate blowdown cycle, it was not possible for the computer to be removed and serviced until after the conclusion of the program. As a result, an Accurex Auto data 980 logger was utilized as backup for periods of data loss for the emissions parameters only. Process data had to be obtained from process log sheets and hand inserted into the data file. Several of the parameters were not logged by the control room and as a result could not be retrieved.

In total, the average emissions data availability for the test program was 95 percent and the valid data capture approximately 93 percent. The lower data capture rate in October was due to the instrument system being taken offline during stratification testing.

During the test program, the mobile laboratory was attended by a full-time operator. On a daily basis, the operator conducted daily calibration checks, performed routine maintenance, accessed the previous day of data (printouts) and filled out daily maintenance check lists and site logs. The major portion of the day was spent reducing data and performing program related paperwork. All data was processed into a field format by the onsite computer.

TABLE 22. SUMMARY OF SYSTEM AVAILABILITY AND EMISSION DATA AVAILABILITY FOR A. B. BROWN NO. 1

Month	# Boiler operating hours	CEM Sampling hardware availability hrs	CEM Sampling hardware availability %	DAS Availability Computer hrs	DAS Availability Computer %	DAS Availability Backup logger hrs	DAS Availability Backup logger %	Data availability hrs	Data availability %
August	624	624	100	390	63	624	100	624	100
September	672	642	96	409	61	672	100	642	96[a]
October	192	192	100	141	73	192	100	180	94[b]

[a] Down time due to pump failure

[b] Data loss was due to stratification testing which takes the instrument system off line.

A time-shared computer was utilized to merge the files contained on the FLUKE System and those acquired by the backup logger. The FLUKE data was transferred directly to storage utilizing a modem link and the backup logger data was hand coded and keypunched for insertion. Other process data not acquired by the backup unit were keypunched onto computer cards from control room log sheets and inserted into the files. Subsequently, a final data report was generated consisting of approximately 22 hours of valid data per day. On a daily basis, one hour was normally consumed during calibration and daily span checks.

STRATIFICATION TESTING

Prior to the initiation of the data collection phase of the program, stratification testing was conducted at each of the four (4) monitoring locations to ensure a representative probe placement. The procedure utilized was previously described in Section 4 of this report.

The results of the initial stratification tests are presented in Table 23 and are listed under the first two test columns designated as "Outlets 7/1" and "Inlets 7/8." Data from this testing sequence were used to locate a point of average concentration in terms of emission rate (ng/J). It was concluded that the probe be placed at port C-2 as noted by the boxed-in values due to the fact that the average concentration of the duct compared fairly well with the value obtained at C-2.

On a monthly basis thereafter, the testing was conducted at the outlet locations only, to verify that the average point remained at the same location. As is shown by the last two tests in Table 23, the average point

TABLE 23. A.B. BROWN STRATIFICATION TEST SUMMARY

	Outlets (7/1)		Inlets (7/8)		Outlets (9/17)		Outlets 10/8	
	Full load		Full load		Low load		Low load	
Port	North	South (ng/J)	North (ng/J)	South (ng/J)	North (ng/J)	South (ng/J)	North (ng/J)	South (ng/J)
A-1	482	224	2973	3107	284	343	283	260
A-2	535	165	2986	3009	285	450	268	208
A-3	555	137	2992	3010	316	328	292	232
B-1	501	193	3114	3060	266	393	276	255
B-2	534	177	3126	2970	289	400	275	252
B-3	503	140	3095	3036	315	389	328	246
C-1	529	180	3029	3067	315	353	320	309
C-2	$\boxed{512}$	$\boxed{182}$	$\boxed{3162}$	$\boxed{3020}$	$\boxed{317}$	$\boxed{376}$	$\boxed{261}$	$\boxed{242}$
C-3	517	151	2964	3039	403	379	344	262
D-1	535	187	3042	3045	*	*	*	*
D-2	423	211	2855	3045	*	*	*	*
D-3	542	170	3012	3065	*	*	*	*
E-1	507	186	3048	3016	*	*	288	278
E-2	494	193	3034	3011	*	*	288	242
E-3	514	162	2864	3030	*	*	310	220
F-1	*	*	2863	3021	312	387	*	*
F-2	*	*	3041	3004	330	387	*	*
F-3	*	*	2781	3010	312	385	*	*
Average	512	169	2999	3031	312	381	294	251
Standard deviation	32	48	103	31	36	31	26	26
C-2/Ave	1.00	1.08	1.05	1.00	1.02	1.01	0.89	0.96

Note: Boxed in values denote present probe placement.

*Port not suitable for sampling.

tends to occur at C-2 which is close to the center of the duct. Further testing was not conducted at the inlet locations because the probability of variable stratification at this location was low.

PERFORMANCE SPECIFICATION TESTS

During the first week of August the proposed performance specifications tests as outlined in the October 10, 1979 and January 26, 1981 Federal Register were conducted to assess the performance of the monitoring system. The performance test criteria were previously listed in Table 13 . Due to a shortage in span gases, the 2 hour drift test was not conducted.

The results of the 24-hour zero and calibration drift tests are listed in Table 24. All analyzers conformed to test criteria for zero and calibration drift except for the NO_x and outlet SO_2 analyzers which exceed the calibration drift criteria.

The Calibration Error test was conducted by initially calibrating all analyzers utilizing five span gases input directly to the analyzers (bypassing all extraction/conditioning components). Subsequently, a calibration equation was calculated as previously described in Section 4. The zero, mid and high span gases were then sampled through the entire extraction system on the north tower only. Results of this test sequence are shown in Table 25. All analyzers conformed to the specified criteria with the exception of the outlet SO_2 analyzer which exceeded the midscale criterion and the NO_x analyzer which slightly exceed the high scale criterion.

Relative Accuracy testing was conducted during the first week of August. The complete relative accuracy test, consisting of greater than nine (9) reference tests, was conducted on the north tower locations only and abbreviated testing was conducted on the south tower (6 runs).

The results of the initial relative accuracy testing are shown in Table 26. Generally speaking, the results were favorable and with the exception of the NO_x results, were less than the stated compliance limit of 20.0 percent in terms of emission rate. For the purposes of this program, data were corrected to emission rates using the O_2 based "F" factor. The results for the NO_x analyzer were in the vicinity of 30 percent in terms of emission rate. The high relative accuracy is the result of a large confidence interval and not absolute bias. This denotes random scatter when comparing the difference between the reference method and the analyzer. Another reason for the high relative accuracy may be the absolute accuracy of Method 7 at levels between 150-200 ppm. At these levels, measurements are being conducted at the lower 15-20 percent of the measurement range where relative scatter becomes significant.

Emission rates for sulfur dioxide were calculated using both the oxygen based and CO_2 based "F" factors. As shown by the results, the two different methods for conducting the calculations did not yield comparable results.

TABLE 24. 24-HOUR ZERO AND CALIBRATION DRIFT SUMMARY

Parameter	Zero drift[a] (%)	Calibration drift[a] (%)
Inlet SO_2 (Horiba)	0.5	1.1
Outlet SO_2	1.6	4.9[b]
Inlet O_2	0.1 (O_2)	0.1 (O_2)
Outlet O_2	0.1 (O_2)	0.2 (O_2)
Inlet NO	0.1	3.3[b]
Inlet CO	0.9	1.3
Outlet CO_2	0.2 (CO_2)	0.3 (CO_2)

TABLE 25. CALIBRATION ERROR SUMMARY

Parameter	Mid (%)	High (%)
Inlet SO_2 (Horiba)	4.1	0.3
Outlet SO_2	9.4[b]	3.6
Inlet O_2	1.5	1.5
Outlet O_2	1.3	3.4
Outlet CO_2	1.7	3.8
Inlet NO	1.6	5.6[b]
Inlet CO	3.2	2.5

[a] O_2 and CO_2 results are presented in terms of O_2 or CO_2 concentrations and not % of full scale.

[b] Denotes exceeded Performance Specifications Test criteria.

TABLE 26. INITIAL RELATIVE ACCURACY TEST SUMMARY

	North tower (%)		(Abbreviated) South tower (%)	
Parameter	Inlet	Outlet	Inlet	Outlet
SO_2	16.9	16.4	28.7	14.8
O_2	0.46% O_2	0.13% O_2	0.53% O_2	0.40% O_2
CO_2	-	0.81% CO_2	-	1.98% CO_2
E_{SO_2} (F_{O_2})[c]	17.3	17.0	28.6[b]	11.8
E_{SO_2} (F_{CO_2})[d]	-	21.0[d]	-	16.1
NO	23.9	-	a	-
E_{NO} (F_{O_2})[c]	36.6[b]	-	a	

[a] Runs Invalidated.

[b] Exceeds criteria.

[c] F_{O_2} = Oxygen based F factor.

[d] F_{CO_2} = CO_2 based F factor.

- Not applicable.

TABLE 27. SEPTEMBER ABBREVIATED RELATIVE ACCURACY TEST SUMMARY

Parameter	North tower (%) Inlet	North tower (%) Outlet	South tower (%) Inlet	South tower (%) Outlet
SO_2	5.5	14.6	12.5	14.7
O_2	0.30% O_2	1.14% O_2	0.14% O_2	0.62% O_2
CO_2	-	2.81% CO_2	-	0.97% CO_2
NO	29.0	-	a	-
E_{SO_2} (FO)	6.1	12.9	12.5	14.2
E_{SO_2} (F_{CO_2})	-	27.9[d]	-	12.8
E_{NO}	31.0[b]	-	a	-

[a] Runs Invalidated.

[b] Exceeds criteria.

[c] FO_2 = Oxygen based fuel factor.

[d] F_{CO_2} = CO_2 based fuel factor.

- Not applicable.

TABLE 28. OCTOBER ABBREVIATED RELATIVE ACCURACY TEST SUMMARY

	North tower (%)		South tower (%)	
Parameter	Inlet	Outlet	Inlet	Outlet
SO_2	21.4	13.5	14.7	18.4
O_2	1.10% O_2	0.55% O_2	1.09% O_2	1.33% O_2
CO_2	-	1.17% CO_2	-	1.14% CO_2
NO	26.5	-	[a]	-
E_{SO_2} (FO)	13.6	14.1	12.8	14.4
E_{SO_2} (F_{CO_2})	-	8.7	-	19.2
E_{NO}	23.9[b]	-	[a]	-

[a] Runs Invalidated.

[b] Exceeds criteria.

[c] FO = Oxygen based fuel factor.

[d] F_{CO_2} = CO_2 based fuel factor.

- Not applicable.

ABBREVIATED RELATIVE ACCURACY TESTS

During the periods of September 12-17 and October 8-10, Abbreviated Relative Accuracy tests were conducted at the inlet and outlet locations of each tower. The results of the two test runs are shown in Tables 27 and 28, respectively. Each of the results are based on at least six replicates. A full relative accuracy test was conducted on the NO_x analyzer during the September test due to the fact that the first set of results were unusually low.

The results from both tests indicate that the monitoring system was generating comparable results since the initial certification test. Results from the NO_x relative accuracy tests continued to yield higher than expected relative accuracies which ranged from 23.9 to 29 percent on a volume comparison basis and 23.9 to 36.6 percent on an emission rate basis.

PRECISION ESTIMATES

Data obtained from the daily zero and span checks were utilized to estimate the precision of the monitoring data. These estimates were calculated using the procedure delineated in the Draft Appendix F Quality Assurance procedures.

The precision results for the program are shown in Table 29 for the SO_2, O_2 and CO_2 analyzers. Estimates for the NO_x and CO analyzers were not calculated due to the fact that a variety of span gases were used for daily zero and spans because of a shortage in calibration gases. The Appendix F procedure requires that the same gases be used or the same gas level. This was not the case with these two monitors.

The results indicate that the precision for all analyzers is consistent; however the outlet SO_2 is much higher than expected. Currently, there are no criteria for precision estimate limits. A zero precision estimate is not required under proposed Appendix F but was included to give the reader an idea of the portion of the span estimate which is attributable to zero drift.

Results for the zero level estimate indicated a consistant operation over the entire test period with the exception of the outlet SO_2 analyzer. This analyzer exhibited precision intervals with ranges from 5.2 to 20.7 percent.

Results for the span precision estimates exhibited the same consistancy as the zero interval for all analyzers with the exception of the outlet SO_2. Interval ranges for this analyzer were much wider than the other analyzers with intervals ranging from 11.6 percent to 25.3 percent. Normal behavior for the other analyzers exhibited precision interval ranges on the order of 5 percent.

One possible explanation for the wider precision interval range exhibited by the outlet SO_2 analyzer relative to the other instruments may be a result of the manner in which the instrument range is electronically selected. The DuPont 400 analyzers are manufactured with the amplifier set to operate in the

TABLE 29. A.B. BROWN PRECISION ESTIMATE RESULTS

Location	Parameter	Month	Zero precision estimate (%)		Span precision estimate (%)	
			Lower	Upper	Lower	Upper
Inlet	SO_2 (Horiba)	August	-0.9	0.5	-1.6	2.3
		September	-0.3	0.8	-1.5	1.5
		October[a]	-0.2	0.8	-0.4	-3.9
	O_2 (MSA)	August	-1.0	0.7	-4.0	1.8
		September	-0.3	0.0	-1.8	1.4
		October[a]	-0.3	0.0	-2.7	1.3
Outlet	SO_2 (DuPont)	August	-7.2	6.1	-16.2	9.1
		September	-8.2	12.5	-8.3	4.4
		October[a]	-2.3	2.9	-6.6	5.0
	O_2 (MSA)	August	0.0	0.5	-2.5	1.7
		September	0.0	0.6	3.7	4.6
		October[a]	-0.1	0.3	0.6	0.8
	CO_2 (Horiba)	August	-0.5	1.2	-4.0	0.8
		September	-0.5	1.3	-2.7	2.5
		October[a]	0.5	0.6	1.8	4.0

[a] Indicates less than 10 entries used for calculating these estimates.

highest range stated. Range changes (to lower ranges) are selected by resistance step changes of the amplifier output. When configured in this manner, range changes to lower ranges result in the noise level being increased by the step change reduction in range. For example, the analyzer utilitized on the A. B. Brown project was capable of range outputs corresponding to 1000, 3000 and 5000 ppm full scale. Since the instrument was operated in the range of 0-1000 ppm full scale, the precision interval is 5 times wider relative to the 1000 ppm range than it would have been if operated in the 0-5000 ppm range. If operated in the 0-5000 ppm range, the precision intervals would be similar to the other instruments which were used during the program.

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